Computer Network Software, Inc.
&
ViaSat Inc.

Multi-function, Multi-mode Digital Avionics Relevant Military Technology Assessment Report

to

NASA GRC

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7405 Alban Station Court, Suite B-215, Springfield, VA 22150-2318
6155 El Camino Real, Carlsbad, California 92009

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EXECUTIVE SUMMARY

NASA's Glenn Research Center (GRC) plans to develop and demonstrate the flexible capabilities of multi-function, multi-mode digital avionics (MMDA) for civil aviation applications such as communications, navigation and surveillance. To support this objective, GRC issued a task order to Computer Networks & Software, Inc. (CNS) to provide an assessment of the applicability and suitability of military software defined radios for civil aviation applications. ViaSat Inc. supported CNS in conducting the research and preparing this report.

This report is an assessment of the applicability to civil aviation of the architectures, components and technologies being developed under the Department of Defense's Joint Tactical Radio System (JTRS) program. The report specifically assesses the applicability of the JTRS Software Communications Architecture (SCA) and the planned JTRS airborne cluster developments to civil MMDA applications.

The JTRS program is developing software-defined radios for ground and airborne usage. The civil aviation equivalent of an airborne unit is an MMDA. The SCA is a key concept that is significantly impacting the design and development of military radios using the JTRS, open architecture concepts and requirements. The SCA for JTRS is shown in Figure ES-1.

While JTRS is focused on resolving interoperability issues and providing enhanced communications capability for Department of Defense (DoD) radio systems, the JTRS approach – particularly the SCA – offers a solution to interoperability problems in many other arenas. JTRS could prove particularly beneficial to civil aviation. JTRS has the potential to provide general aviation users with a low-cost, SCA-compliant capability for air and surface transmission of position, weather, traffic conditions, etc. with parameters akin to the capabilities to be provided by the Universal Access Transceiver (UAT).

The heart of this investigation centered on the applicability of the JTRS architectures and technology to the MMDA design. The cluster (architectures) examined most comprehensively were those closest in application to that of MMDA, which is multi-function avionics. In the JTRS program the avionics design has the additional challenge and requirements concerning the installed environment, power dissipation and Electromagnetic Interference (EMI) performance. These are also critical to MMDA success. The assessment examined each facet of the JTRS approach including the basic open hardware design, SCA/CORBA software approach, and hardware partitioning and performance issues when applying technology to the commercial realm. Additionally, issues concerning system performance were also examined including processor throughput and processor loading.

As shown in Table ES-1, JTRS has five waveforms with direct applicability to the civil aviation environment. They are HF ATC Data Link, VHF-AM ATC, VHF-AM ATC Extended, VHF ATC Data Link (NEXCOM), and STANAG 4193 Mode S Level 4/5. These waveforms will allow military aircraft to operate within the civil environment controlled by the FAA or similar agencies in Europe and Asia.

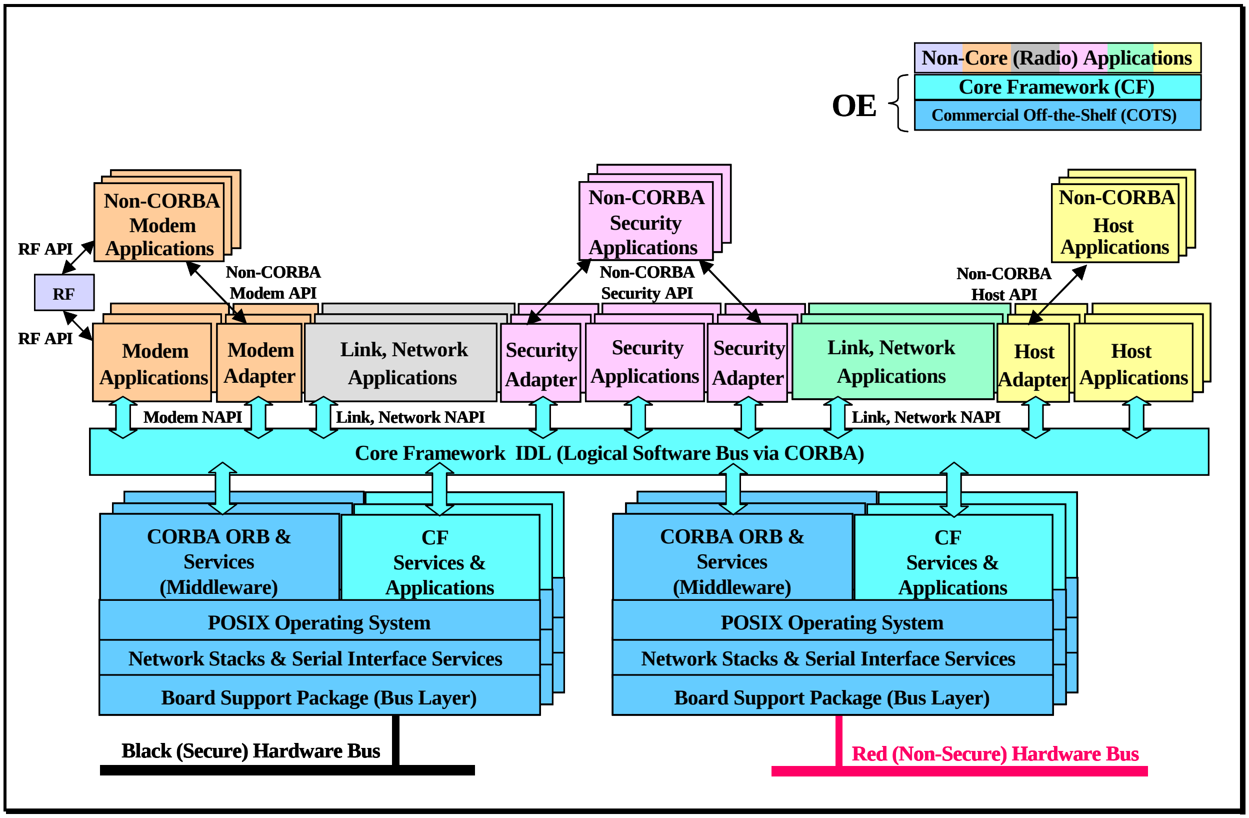

Figure ES-1. Software Communications Architecture for JTRS

Other waveforms also may be applicable to the MMDA design. The objective of the software radio is to be upgradeable into the extended future of 2015 and beyond. Waveforms that have not yet been developed may eventually be added to the system to meet the emerging requirements of the next decades.

Beyond JTRS, a number of historical programs including Integrated Communications, Navigation and Identification Avionics (ICNIA), F-22 Communications, Navigation and Identification (CNI), RAH-66 CNI and F-35 CNI were also examined. These programs designed very complex, multi-band, multi-function communications systems and provide "lessons learned" that can apply to an MMDA program. This is especially true in reducing the risk of qualification and certification. Many of these historical programs experienced significant backend risk in qualification due to limitations in hardware, software or architecture. Until the Joint Strike Fighter (F-35 CNI), many of the historical programs suffered from point hardware designs and busses, which caused a significant risk to integration plus test and qualification. F-35 CNI is required to be JTRS, SCA/CORBA compliant. However, this program was initiated before many of the SCA/CORBA definitions were complete. The F-35 CNI version of architecture, along with the Link JTRS architecture, provides a solid departure point for analyzing an MMDA architecture based on JTRS compliance. Additionally, other software defined radio programs were examined for key technologies, concepts, architectures and performance issues. These programs included efforts from MITRE, Rockwell Collins, and General Dynamics. A summary of these programs is included Table ES-2.

Table ES-1. JTRS Waveforms

ID	KPP (K)	ID	THRESHOLD (T)	ID	OBJECTIVE (O)
W1	*SINCGARS ESIP (VHF-FM Military Tactical AJ)	W7	UHF SATCOM Military Protocol (184)	W30	MSS [Waveform Family]
W2	*HAVE QUICK II (UHF-AM/FM/PSK Military Tactical AJ)	W8	HF-ISB ALE	W32	BOWMAN (UK HF/UHF Military Tactical) [Waveform and Equipment Family]
W3	*UHF SATCOM Military (181-182-183 “DAMA”)	W9	HF-SSB ALE AJ		
W4	*EPLRS	W10	Link-11 / TADIL-A		
W5	*WNW	W11	STANAG 5066 (HF Message Protocol)		
W6	*Link 16 / TADIL-J	W12	STANAG 4529 (HF NB Modem)		
		W13	VHF-FM – Military Tactical		
		W14	HF ATC Data Link		
		W15	VHF-AM ATC		
		W16	VHF-AM ATC Extended		
		W17	VHF/UHF-FM LMR: (Land Mobile Radio & Public Safety w/ Project-25 and TETRA) [Waveform Family]		
		W18	VHF ATC Data Link (NEXCOM)		
		W19	UHF-AM/FM/PSK Military Tactical		
		W20	Link-4A / TADIL-C		
		W21	Link-11B / TADIL-B		
		W22	SATURN (UHF PSK AJ NATO)		
		W23	STANAG 4193 Mode S Level 4/5		
		W24	DWTS (UHF PSK WB LOS)		
		W25	Soldier Radio & WLAN & Advanced Capability [Waveform Family]		
		W26	COBRA		
		W27	MUOS-CAI (UHF SATCOM Military Obj.)		
		W28	Cellular Radio & PCS [Waveform Family]		
		W29	Link 22 / NILE		
		W31	IBS-M		
		W32	BOWMAN (VHF)		

Table ES-2. Pertinent Historical Programs

Program	Participating Companies	Application	Dates	JTRS or SCA Compatibility
ICNIA	TRW Rockwell Collins Singer Kearfott	Military	1983 – 1989	No
YF-22 DEM/VAL	Lockheed Martin TRW Rockwell Collins GEC Marconi	Military	1988 – 1990	No
F-22 CNI	Lockheed Martin TRW Rockwell Collins BAE Harris ITT Avionics	Military	1991 – 2001	No
RAH-66 Comanche CNI	Boeing TRW Rockwell Collins BAE	Military	1996 – 2004	Partial
F-35 CNI	Lockheed Martin Northrop Grumman Rockwell Collins	Military	2002 – 2012	Partial
Modular Digital Radio	General Dynamics	Military	1996 – 2004	Partial
Software Defined Radio	Mitre	Commercial	on-going	Yes
JTRS/SCA	Rockwell Collins	Commercial	on-going	Yes
JTRS	Various	Military	on-going	Yes
NEXCOM VDL Modes 2, 3	ITT	Commercial	on-going	Partial
AN/ARC-210	Rockwell Collins	Military	on-going	No
VDL 2000	Rockwell Collins	Commercial	on-going	No
NEXCOM UHF	General Dynamics	Commercial	on-going	Partial
NEXCOM Ground System	Harris	Commercial	on-going	Partial
Software Radio 3.3	Australian Telecommunications	Commercial	1999 – 2001	No
Radio Description Language of SCA	Vanu Inc	Military	2002	Yes
US Navy Speakeasy	ITT	Military	1992 – 1998	No
ARINC 750 VDL/CMU	Honeywell TRW	Commercial	1998 – 2000	No

The Statement of Work requested that four areas be addressed in the assessment. The first three are discussed below. The fourth is covered in Appendix B. For the first three, a number of pertinent questions are posed and discussed followed by a recommendation.

1. JTRS waveforms and/or architectures that meet current and emerging avionics standards

2. Areas of concern or challenge where JTRS does not address civil avionics standards

3. Certification aspects facing the use of JTRS waveforms and/or SCA architecture in civil aviation

4. Working groups and key individual contacts associated with certification aspects of aircraft equipped with JTRS capability to operate in FAA-controlled airspace

1. JTRS Waveforms and/or Architectures that Meet Current and Emerging Avionics Standards

The completed review of current JTRS waveforms indicates that five waveforms currently under contract are applicable to civil aviation requirements. These waveforms will be certified for use on military aircraft flying in civil airspace and are directly applicable to a commercial MMDA radio. The waveforms are:

- HF ATC Data Link
- VHF-AM ATC – Voice
- VHF-AM ATC Extended – Navigation (VOR/ILS)
- VHF ATC Data Link (NEXCOM)
- STANAG 4193 Mode S Level 4/5 – Surveillance (1030/1090 MHz Transponders)

The JTRS program is not expected to meet civil aviation standards (RTCA or AEEC) in its hardware components, but is expected to meet civil aviation waveform functions. The component that JTRS is developing applicable to civil aviation is the waveform definitions and software. A discussion of the use of the DoD product waveforms by civil aviation is found in section 2.4.3.2. The certification of these waveforms and the SCA architecture are discussed in section 2.4.3.3.

The NEXCOM program has defined the ATC VHF Data Link waveform. However, this waveform may be an open venue for NASA and FAA cooperation.

As the JTRS program progresses, additional waveforms may be developed and used on an MMDA type of radio. It is anticipated that development of new waveforms would take at least five years to complete.

The commercialized architecture (described in section 2.3.4, MMDA Implementation with a Civil Airborne Domain JTRS Architecture) uses the current elements of the JTRS architecture (including SCA software architecture and CORBA services) to accomplish a commercial set of functions for a software defined radio. This architecture, however, requires additional cost/benefit and physical partitioning analysis to tailor it for civil applications.

2. Areas of concern or challenge where JTRS does not address Civil Standards

What will the JTRS concept packaged for civil applications cost?

Discussion. Table ES-3 indicates what civil aviation can be expected to pay for discrete radio related avionics. The costs shown are expressed as ranges and are based upon the study team's experience. Installation, training and retrofit costs are additional.

Table ES-3. General Cost Ranges for Radio Related Avionics

Category	Item Purchase Price Range ($)	Remarks
Air Transport (wide and narrow body)	Radio VHF AM: 30 – 50K CMU: 100 – 150K	Voice and Communications Management Unit (CMU) for data link (dual or triple redundancy is required)
Business Jet	Use same units as air transport	
Regional	Normally voice radio voice only 25 – 40K	CMU/Radio new offerings in the 30 – 50K range now available
General aviation – Upper End	1,000 – 3,000	
General Aviation	500 – 1,000	

One program element of JTRS has targeted the end system for the mobile user at a $200,000 price point. However, there is no assurance that this target will be achieved nor is the support cost known to be reasonable. It appears that meeting the civil target price ranges with any of the military produced JTRS radio systems will be very unlikely.

The cost effectiveness of the JTRS approach is to package several radios within the same MMDA enclosure and thus yield a reduced amount of avionics equipage. The discrete radio package prices of Table ES-1 have to be compared to the aggregate cost of having a number of radio capabilities within the single JTRS. This is a function of the class of user and the number of radio related avionics normally carried. The analysis of these tradeoffs is beyond the scope of the current study. However, it is not apparent that a civil affordable unit will be produced within the military-led JTRS program. This means that any use of the JTRS architecture standards will require a new end system design effort – although this new design may reuse some of the current or expected JTRS components.

Recommendation. NASA should foster a "designed to unit cost" analysis to be an integral work task for any prototype development project of a MMDA unit that will incorporate the JTRS approach. A step in this analysis will be to conduct a cost study to determine if a mix of integrated avionics and price point is justified.

Will civil aviation (air transport, business and general aviation) adopt the software portability and standard open architecture concept of the JTRS as the means to achieve interoperability?

Discussion. The heart of interoperability in JTRS is based upon portable (standardized) waveforms. There is little of a parallel in civil aviation for this vendor-to-vendor portability. However, two avionics related software components show that the civil industry may adopt a similar principle, provided the end product is reasonably priced. The examples are the Tactical Collision Avoidance System (TCAS) and the government-led Aeronautical Telecommunications Network (ATN) router program of the late 1990s. In each case the government supported software products that were then made available to all. The TCAS approach should be reviewed to determine how well the concept is working.

Recommendation. NASA should foster an industry activity to review the use of a common waveform concept and to foster government leadership in establishing the approach.

Can the JTRS be developed to use ISO TP4/CLNP protocols of the currently defined ATN?

Discussion. Adding the International Organization for Standardization (ISO) protocols to the JTRS is a requirement if the adoption of the current ATN standards proceeds. It does not appear that military planners intend to add the Transport Protocol Class 4/Connectionless Network Protocol (TP4/CLNP) required by the ATN standards as the VHF ATC Data Link.

Recommendation. NASA should continue to foster the work to move the Airlines Electronic Engineering Committee (AEEC) and International Civil Aviation Organization (ICAO) to adopt Transport Control Protocol/Internet Protocol (TCP/IP) as the transport and network protocols for the aviation air-to-ground data links. If they are adopted, then ATN over IP will ease the use of a JTRS approach.

Is the Multi-level Security concept with the JTRS useful to industry?

Discussion. The JTRS architecture makes use of information processing using multi-level security (MLS) and trust labels as the means to keep users and application data compartmented. The parallel in civil aviation is partitioning according to the critically of the flight information being handled. The software development for higher levels of flight critically is increasing rigorous. Use of the MLS may provide a technique to reduce cost, but would impose a scurity function on all processes. The technique would have to be introduced into all air traffic and airline information handling systems. This would be a large transformation to attempt. Lastly, it is not clear if the government would release components and processes for general use. A “watered down” version of the concept may be required.

Recommendation. NASA should research this area to determine potential benefits and to determine if the JTRS approaches to encryption and MLS have merit in the civilian environment.

Will the aviation community support and ask for development of an MMDA buyer’s standard that includes the concepts of the JTRS, but defines the form, fit, and function for an aircraft swappable item?

Discussion. There isn't an on-going effort to adopt the JTRS architecture and waveform portability as a standard for civil avionics. The need to define the design considerations and certification guidelines for Integrated Modular Avionics (IMA) is being fulfilled by RTCA SC-200. Typically, the airline community will define a common "form, fit and function specification" for avionics units/functions that are considered to have common use across different aircraft types. This includes interface connectors. Through this standard process, the airlines improve strength in buying power as well the ability to use avionics on different aircraft types.

Recommendation. NASA should consider fostering a standards effort to include the definition of an avionics unit following the JTRS architecture and waveforms portability principles.

3. Certification aspects facing the use of JTRS waveforms and/or SCA architecture in civil aviation

Is there any FAA certification legacy that can be claimed upon completion of the military programs?

Discussion. This concern area is addressed in paragraph 2.4.3.3.

Analysis of Certification Aspects

Discussion. The open question not addressed in this assessment until now is, "Will DoD conform to FAA certification standards?" From analysis we see three potential program paths for civil portability of the JTRS waveforms and related hardware.

- NASA should foster and sponsor early support from the FAA to guide JTRS development to meet current and future FAA certification standards. This would involve development of the application software to meet the goals of RTCA DO-178B and development of the hardware to DO-254 standards.

- NASA should develop a bridge between DoD and the FAA certification process. This would entail allowing certain aspects of DoD's rigorous testing to meet or exceed FAA standards and establishing agreements with the FAA that such testing is acceptable. In addition, NASA should work to develop an agreeable plan to meet FAA certification requirements of those artifacts that do not comply with FAA standards. This would involve building a direct correlation between the DoD qualification methodology and the FAA certification policies. DoD and the FAA would have to agree that the middle ground is acceptable.

- Because of the projected costs of developing JTRS compliant hardware, NASA should establish a program to develop its own platform with the intent to amend certified MMDA hardware in civil aviation. In light of starting from scratch, waveform development and government ownership (either NASA or FAA) of the waveform would leverage the objectives of the JTRS program.

1. INTRODUCTION

NASA's Glenn Research Center (GRC) plans to develop and demonstrate the flexible capabilities of multi-function, multi-mode digital avionics (MMDA) for civil aviation applications such as communications, navigation and surveillance. To support this objective, GRC issued a task order to Computer Networks & Software, Inc. (CNS) to provide an assessment of the applicability and suitability of military software defined radios for civil aviation applications. ViaSat Inc. supported CNS in conducting the research and preparing this report.

For the purposes of this task, the term, "multi-function" refers to multiple communications, navigation and/or surveillance functions that can be performed by avionics either sequentially or simultaneously (e.g., VHF Digital Link [VDL] communications, Global Positioning System [GPS]-based navigation, and/or Automatic Dependent Surveillance Broadcast [ADS-B] transmissions). "Multi-mode" refers to the capability to perform sequentially, two or more operational modes of a given communications, navigation or surveillance function (e.g., communications via either VHF analog voice mode or VDL Mode 2). "Digital avionics" refers to onboard aircraft electronics hardware and software that are either software defined or re-configurable for multiple functions and/or modes of operation.

The current and planned avionics and associated technologies assessed under this task apply to a wide range of aircraft classes including commercial carrier and cargo transport aircraft, business jets, general aviation, and military aircraft.

GRC's intent is to use the assessments performed under this task to identify the role NASA can uniquely assume to help:

- Leverage and advance the state of the art in avionics technology
- Reduce the cost, size and power consumption of commercial avionics
- Improve the flexibility and capability of avionics to interoperate with existing and future international standards
- Reduce the time and cost to initially certify and potentially re-certify aircraft with software-defined avionics in the future

1.1. Scope

This report contains an assessment of the applicability to civil aviation of the architectures, components and technologies being developed under the Department of Defense's Joint Tactical Radio System (JTRS) program. The report specifically assesses the applicability of the JTRS Software Communications Architecture (SCA) and the planned JTRS airborne cluster developments to civil MMDA applications.

The report includes information about the following as required by the Statement of Work.

- JTRS waveforms and/or architectures that meet current and emerging avionics standards

- Areas of concern or challenge where JTRS does not address civil avionics standards

- Certification aspects facing the use of JTRS waveforms and/or SCA architecture in civil aviation

- Working groups and key individual contacts associated with certification aspects of aircraft equipped with JTRS capability to operate in FAA-controlled airspace

This report also identifies and summarizes past and current programs relevant to the MMDA, software defined radios, integrated communications, advanced software and digital technologies. It includes the following information:

- Identification of past programs with applicable approaches
- Identification of current programs with applicable approaches
- JTRS overview
- Analysis of the architectures in past and current programs
- Analysis of the application of the JTRS architecture to MMDA
- Recommendations for an MMDA architecture and approaches

The focus of this study is to collect data pertinent to software defined radios and provide recommendations as to the approaches, technologies, requirements and lessons learned. Additionally, a thorough examination of the JTRS program and its architectures provide a starting point for a commercial MMDA architecture. The outcome of the study data collection, analysis and recommendations are which portions of these programs can be directly applied to MMDA. It should be noted that the term portions is used because many aspects of military architectures would be too cumbersome and expensive to implement in a commercial situation.

1.2. Joint Tactical Radio System (JTRS)

The Department of Defense’s Joint Tactical Radio System (JTRS) program is developing software-defined radios for ground and airborne usage. The civil aviation equivalent of an airborne unit is an MMDA. The Software Communications Architecture (SCA) is a key concept that is significantly impacting the design and development of military radios using the JTRS, open architecture concepts and requirements.

The SCA is today, the most significant manifestation and realization of the Software Defined Radio concept. As a point of fact, the SCA has already been adopted on significant projects. The SCA provides a framework that supports an industrial resource-based and component-based approach to build versatile radio sets, each offering several configurations. Furthermore, some of the waveform related Application Program Interfaces (APIs) are specified in the Object Management Groups SCA API supplement document. However, it must be recognized that the

SCA is more focused on management and control facilities than to provide radio business services for waveforms developers, and the API supplement is far from being complete.

Also, the SCA model is not platform independent and is intimately embedded with Common Object Request Broker Architecture (CORBA). It is worth noticing that the SCA concepts and even the CORBA Component Model (CCM) concepts gracefully match the Open Systems Interconnection (OSI) ones in several ways:

- The OSI Service Access Point can be mapped upon the SCA and CCM Port concept
- The Application Service Elements can be mapped upon the SCA and CCM Interfaces concept
- SCA packet and payload concepts in the waveform supplement maps to a Packet Data Unit (PDU) and a Service Data Unit (SDU) in the OSI model
- There is also a many-to-many relationship between the component concept in SCA and layer concept in the OSI model in the sense that a single layer may be comprised of multiple components, or a single component may be deployed as a part of a waveform layer. Both SCA components and OSI waveform layering together with Service Access Points (SAPs) provide functional boundaries and standard access to waveform facilities.

The SCA for JTRS is shown in Figure 1-1. As can be seen, CORBA is a key component of the architecture. CORBA implementation has challenges in the military world. CORBA was defined as a commercial standard, which has introduced limitations to military technology. CORBA introduces design limitations for commercial avionics technology pertaining to data and network security. It should be noted that a key objective of the SCA architecture is to separate data of differing security levels. This isolation is key to allowing multiple functions with different levels of security (multi-level security) to operate in a single system simultaneously.

While JTRS is focused on resolving interoperability issues and providing enhanced communications capability for Department of Defense radio systems, the JTRS approach – particularly the Software Communications Architecture – offers a solution to interoperability problems in many other arenas. JTRS could prove particularly beneficial to civil aviation. JTRS has the potential to provide general aviation users with a low-cost, SCA-compliant capability for air and surface transmission of position, weather, traffic conditions, etc. with parameters akin to the capabilities to be provided by the Universal Access Transceiver.

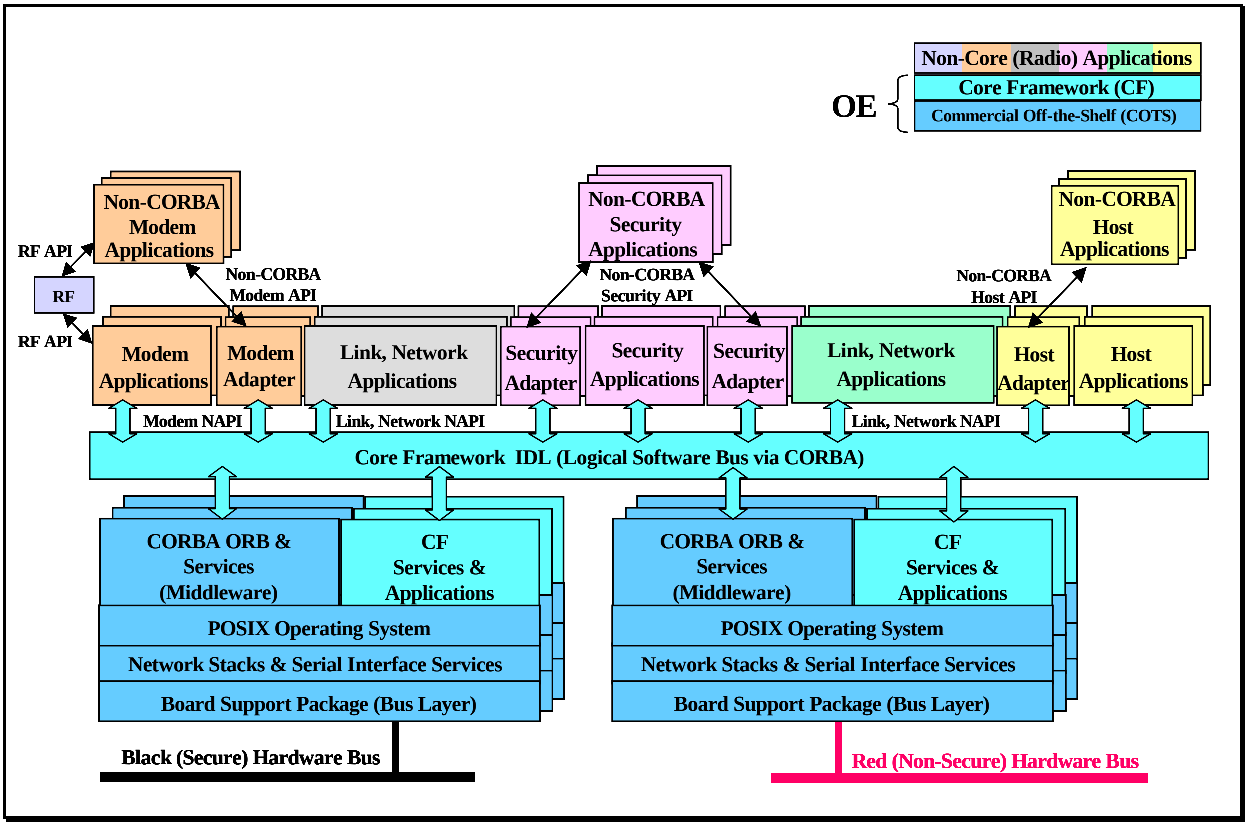

Figure 1-1. Software Communications Architecture for JTRS

As can be seen in Table 1-1, there are waveforms being developed for JTRS that would apply to commercial and general aviation. They include:

- HF ATC Data Link
- VHF-AM ATC – Voice
- VHF-AM ATC Extended – Navigation (VOR/ILS)
- VHF ATC Data Link (NEXCOM)
- STANAG 4193 Mode S Level 4/5 – Surveillance (1030/1090 MHz Transponders)

Additional waveforms may be applicable to the MMDA design. The objective of the software radio is to be upgradeable into the extended future of 2015 and beyond. Waveforms that have not yet been developed may eventually be added to the system to meet the emerging requirements of the next decades.

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		W28	Cellular Radio & PCS [Waveform Family]		
		W29	Link 22 / NILE		
		W31	IBS-M		
		W32	BOWMAN (VHF)		

1.3. Document Organization

Following this introductory section, Section 2 provides the results of our survey and assessment. It covers current and near term avionics architectures, a product and architecture survey, an analysis of current efforts in developing a roadmap for MMDA, and an analysis of past and current programs as to their applicability to MMDA. Section 3 presents our recommendations. Appendix A is a listing of acronyms and Appendix B contains contact information for JTRS personnel and activities.

2. SURVEY AND ASSESSMENT

This section provides detailed information related to the architectures, approaches and technologies for software defined radios, especially the Joint Tactical Radio (JTR) Program. Each relevant program is described in a summary manner and relevant approaches or lessons learned are outlined dependent on the applicability to the MMDA design approach. It should once again be noted that programs claiming to be software defined radios but failing to meet the criteria of multi-function, multi-band were examined but not presented in detail. MMDA will be an avionics application requiring the certification of software and hardware for aircraft use. Requirements for these types of program are more rigorous than those of the ground system counterparts. Therefore, these types of historical programs provided the most relevant information. Each program was analyzed and examined for:

- SCA/CORBA requirements
- Integrated, common open architecture for hardware and software
- Upgradeability paths
- Certification issues
- Key technical contributions
- Key technical failures or shortfalls
- Key lessons learned applied to future products/projects

Before addressing the future MMDA architecture, some the current and near term avionics architectures are investigated. These architectures are presented next.

2.1. Task 2 - Current and Near Term Avionics Architectures

The CNS avionics architecture can be thought of as consisting of three functional elements and an infrastructure that binds the various functional elements. The three avionics functions are the radios, applications and flight deck displays. The radio consists of the communication radios, navigation radios, sensors, transponders and radar that form the media that transport the application data. The applications are the communication, navigation and surveillance functions. For example, some of the communications functions are data link management, protocol translation, message routing, and network management. Some of the navigation functions are flight planning, predictions, guidance, and navigation. Some of the surveillance functions include terrain, traffic, and weather and conflict detection. The flight deck displays include Multipurpose Control Display Unit (MCDU), Primary Flight Display (PFD), Multifunction Flight Display (MFD) and Electronic Flight Bag (EFB).

To design, develop and implement an optimal MMDA architecture, one needs an in-depth understanding of existing avionics architectures. In the following sections two architectural approaches (one based on ARINC Report 660A and the other based on ARINC 664 Part 5) are presented.

2.1.1. ARINC Report 660A Avionics Architecture

Future avionics architectures have to take into account the requirements of various stakeholders as well as advancements in technology. ARINC Report 660A, CNS/ATM Avionics, Functional Allocation and Recommended Architectures, is an outgrowth of the original ARINC 660 document that identifies and specifies the aircraft avionics functions necessary for operation in the emerging Communications, Navigation and Surveillance/Air Traffic Management (CNS/ATM) environment.

This report defines the avionics architectures that would apply to new and retrofit aircraft, while recognizing that the recommended architectures will vary as a function of the existing avionics baseline. To achieve this goal, what is needed is an architecture based on open standards that can meet not only certification and safety requirements but also the needs of the key players. The key players include airlines, airframe manufacturers and avionics suppliers. To develop a successful future avionics architecture, a number of factors has to be taken into account. Some of these factors are discussed before the architectures are presented.

The avionics architecture and the ultimate configuration have to be developed in advance for future aircraft. Therefore, the design should minimize the need for customization and service bulletins that may emerge after the start of production. In addition, the same upgrades developed for aircraft in production should be readily available for retrofit. Therefore, new aircraft designs should include an "open" avionics system architecture that allows for sufficient functional independence. In this type of architecture, it should be possible to update, modify or add functionality with minimal impact on other systems.

Aircraft system certification is another critical factor that has to be taken into account in the design of the next generation avionics architecture. As the CNS/ATM infrastructure develops, software configurations will be influenced by aircraft type and aircraft route structure. It is recognized that the certification and operational approval process has become a complex task in the CNS/ATM operational environment because of the need to ensure end-to-end integrity of data link applications. In addition, the same data link applications need to be developed with the utmost concern for the human factors interface in the cockpit. The avionics architecture should be designed to facilitate the necessary system integration and standards compliance testing for safety analysis, verification and validation test, requirements of RTCA DO-178, and other requirements necessary to satisfy national and international regulations. Significant cost reductions will only occur if a large degree of software commonality is achieved across multiple fleet types. This can be achieved through the development of common functional and operational standards.

It is recognized that CNS/ATM functionality will be evolving over time. Therefore, it is imperative that the CNS/ATM architecture, hardware and software support this change in a manner that minimizes not only the initial acquisition cost but also the ongoing cost of ownership associated with the evolving CNS/ATM environment. To this end, the airlines encourage the following concepts be applied throughout the development of the avionics.

- The use of standardized software packages is encouraged to broaden the application base. Standardization will facilitate software reuse and amortize software development costs over multiple implementations. This will effectively reduce the cost of each application. The reuse of flight software on non-airborne platforms may also facilitate the development of low-cost training devices.

- The hardware platform should be flexible and capable of hosting application software that can be easily modified by the manufacturer. It should also allow the user to select options, customize or characterize the avionics without the need to alter the software.

- Partitioning should segregate hardware and software into logical and manageable entities, providing sufficient isolation such that changes within a partition or additions of new partitions do not affect the other partitions. This approach allows for step-by-step implementation and a reduction in the overall change cost by significantly reducing the testing of the unaffected partitions. Hardware and software partitioning becomes especially important as systems grow larger with more integrated functionality. ARINC Report 651 provides guidelines for hardware and software partitioning.

- The CNS/ATM equipment must provide a built-in growth capacity to accommodate and support the anticipated full CNS/ATM function set. The CNS/ATM architecture must provide optimal reliability and availability to reduce life cycle cost to the airlines. Fault tolerant design and redundant configurations should be considered in the design process, optimized for cost versus functionality.

- The CNS/ATM architecture must support design and integration standards that facilitate simplified maintainability.

ARINC Report 660A, CNS/ATM Avionics, Functional Allocation and Recommended Architectures, is an outgrowth of the original ARINC 660 document. It identifies and specifies the aircraft avionics functions necessary for operation in the emerging CNS/ATM environment. Advanced avionics equipment architectures, functional definition and functional allocation are included. This report defines the avionics architectures that would apply to new and retrofit airplanes, recognizing that the recommended architectures would vary as a function of the existing avionics baseline. Figure 2-1 presents the CNS top-level functional architecture. It consists of the communication subsystems, applications, and display and storage subsystems.

Figures 2-2, 2-3, and 2-4 present the communication, navigation and surveillance functional architectures. These architectures identify the functions identified in ARINC Report 660A.

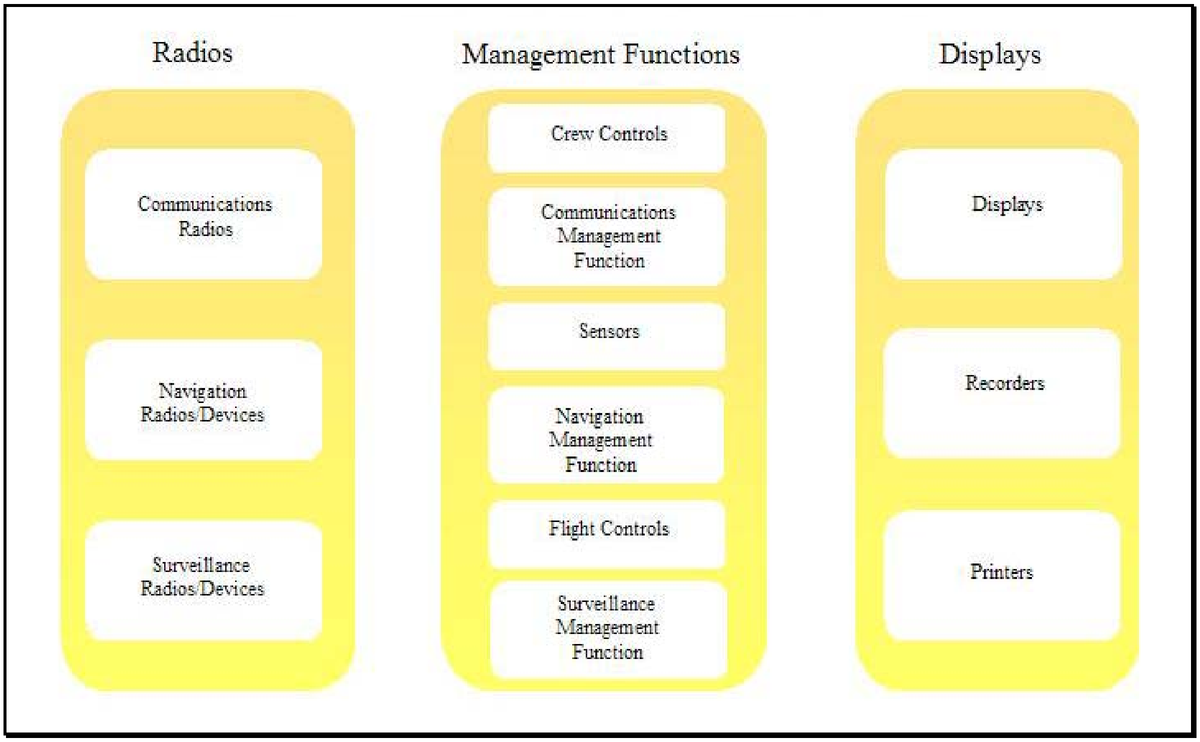

Figure 2-1. CNS Top Level Functional Architecture

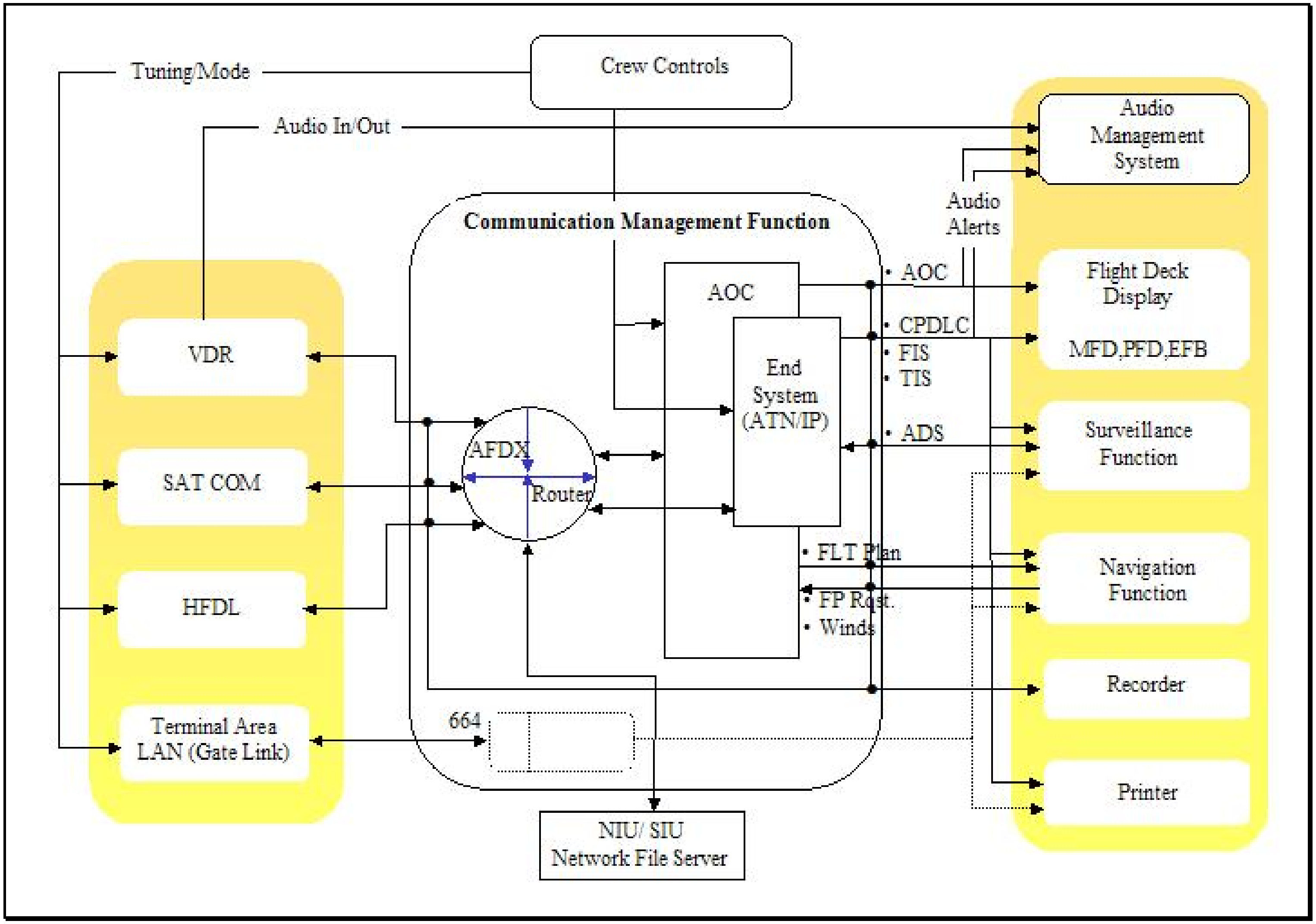

Figure 2-2. Communication Functional Architecture

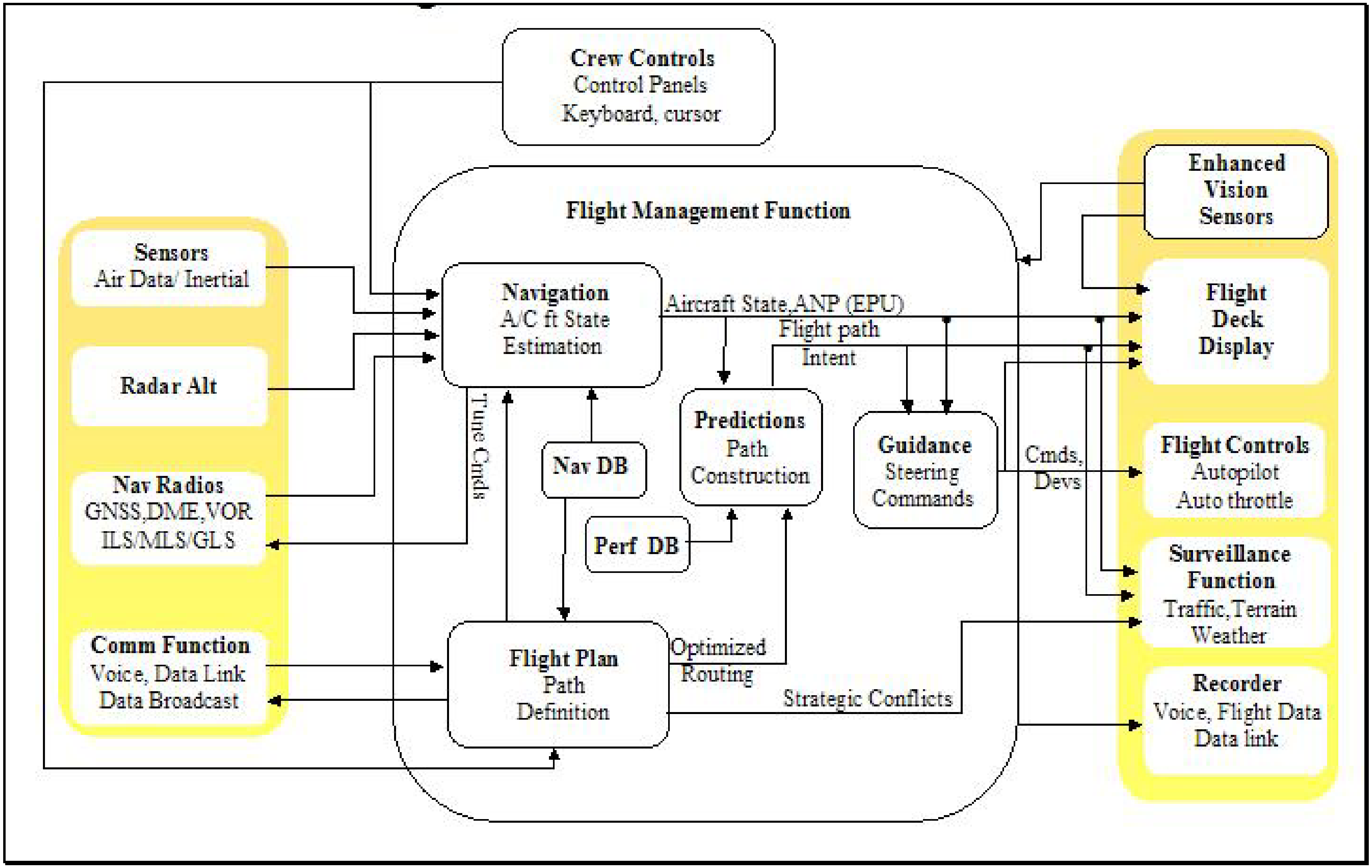

Figure 2-3. Navigation Functional Architecture

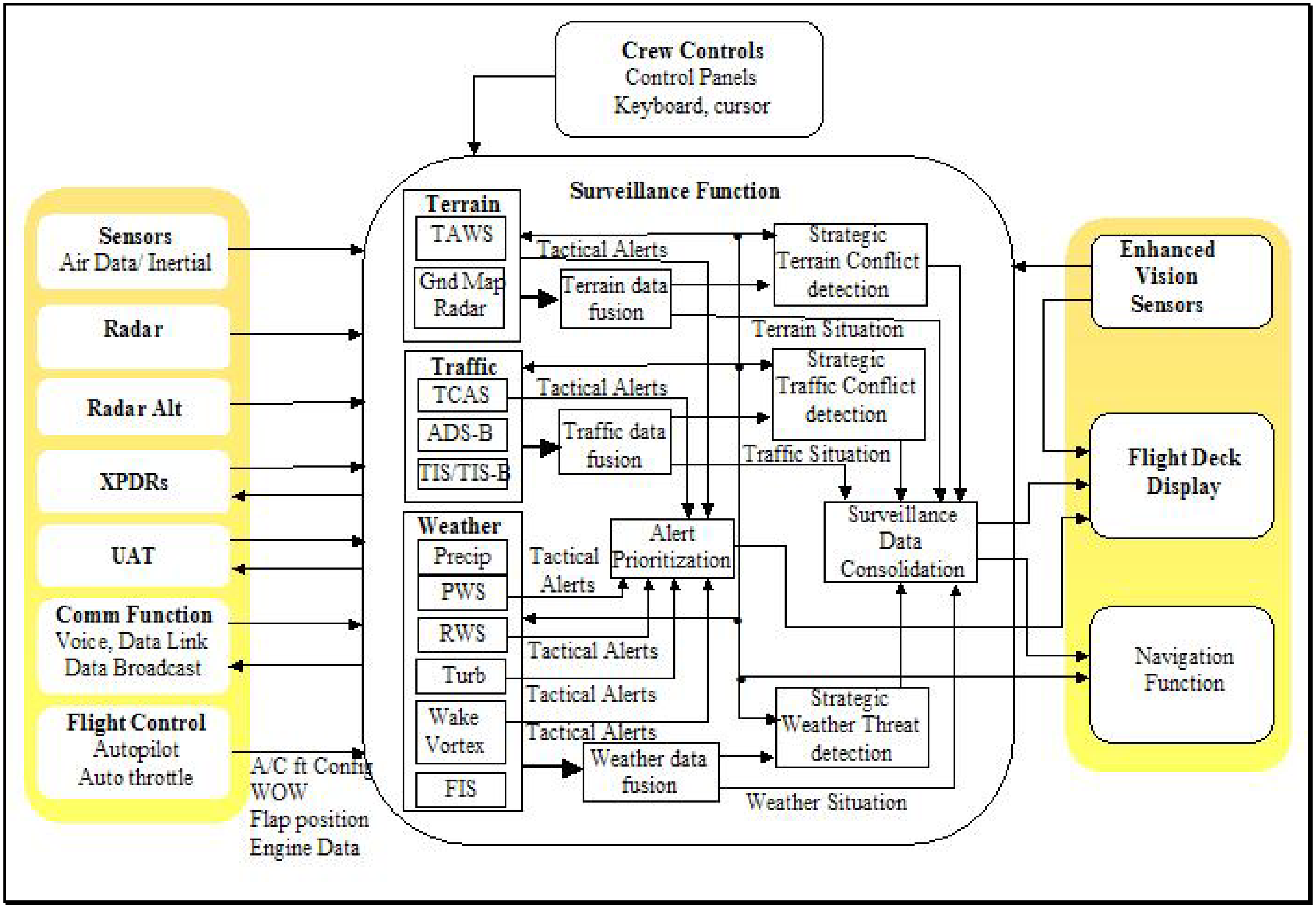

Figure 2-4. Surveillance Functional Architecture

2.1.2. Domain Based Architecture

ARINC Specification 664, Part 5 involves an aircraft architecture based on aircraft control and information domains. The Aircraft Control and Information Services Domains can be divided into sub-domains. Figure 2-5 presents various domains in the domain-based architecture. The Aircraft Control Domain (avionics domain) can be broken down into a Flight and Embedded Control System sub-domain where the aircraft is controlled from the flight deck and a Cabin Core sub-domain that provides environmental control of the aircraft from the cabin.

The Information Services domain has two sub-domains. One provides operational and airline administrative information to both the flight deck and cabin. The other provides information that for the passengers. The In-Flight Entertainment (IFE) domain is usually provided by a single supplier and is not broken down further in this reference architecture. Passenger Devices are not actively managed but need to be taken into account for security and power considerations.

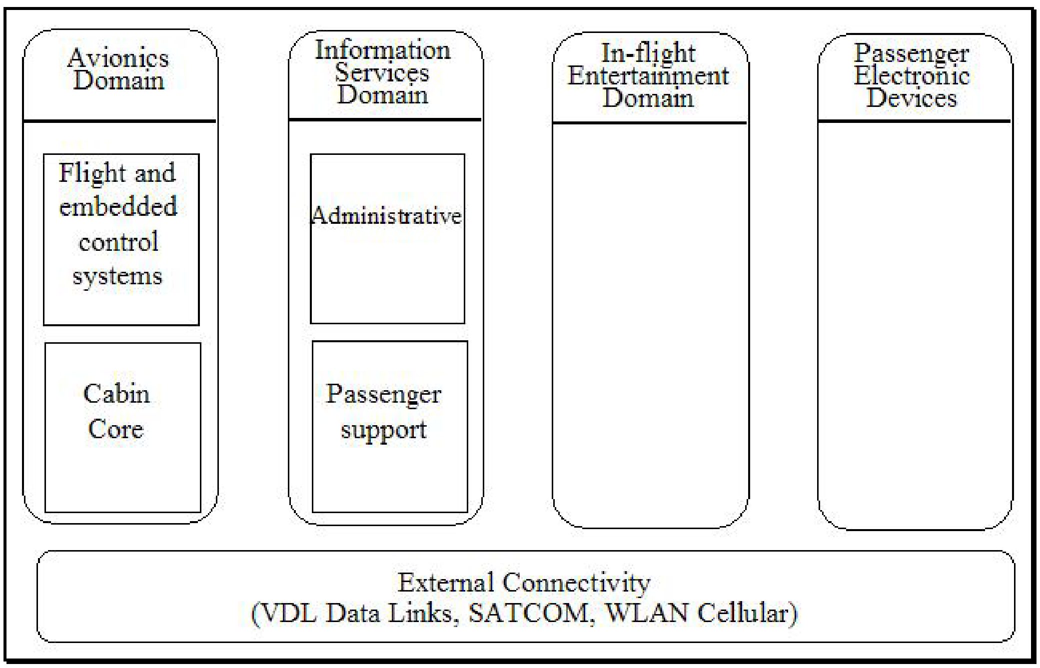

Figure 2-5. Domain Based Architecture

2.1.2.1. Avionics Domain

The avionics domain consists of systems and networks whose primary function is to support the safe operation of the aircraft. The avionics domain is primarily focused on digital, and more specifically, Internet Protocol (IP) data and networks. The justification for most of these systems is traceable to safety of flight. When these systems perform non-safety related functions, it must be shown generally that no interference with safety related functions is possible.

The avionics domain may also provide services and connectivity between independent aircraft domains such as the information services, in-flight entertainment, cabin distribution and any connected off-board networks. The avionics domain may impose requirements on lower-criticality domains, but must always protect itself. Off-board communications for the avionics domain aligns with the safety related characteristics of the domain in general. ATC and some Aeronautical Operational Control (AOC) communication are considered high priority and other uses are based on non-interference with high-priority usage. Currently, avionics off-board communication links are almost exclusively either analog or non-IP digital. However, an off-board IP link is a reasonable possibility in future airborne network architecture. A complicating factor for avionics is that while all air transport aircraft can be assumed to have an “avionics domain”, there is a tremendous variety of systems and network architectures used in avionics. This means that characteristics internal to the domain can only be described in general terms. With appropriate assumptions, characteristics of data flows in and out of the domain can be described in more detail. However, the specific implementation and network capacity will of necessity vary widely depending on the aircraft model and specific configuration.

While the information services domain is relatively new and has little fleet penetration and IFE systems are typically updated and even replaced over time, avionics systems designs change relatively slowly. Wholesale replacement with a completely new system is extremely rare. This must be kept in mind when looking at fleet wide implementations of new functionality.

The fundamental principle for general IP interfaces with avionics is that non-interference with safety related functions must be shown for any implementation. This includes safety-related communications functions. Today, the majority of avionics systems interface to IP networks only at the perimeter of the domain. An avionics system must either provide a robust partition that prevents interference in shared transport services or must assure that data flows are appropriately controlled. Examples of systems in the avionics domain include:

- Cockpit Displays
- Flight Controls
- Environmental Controls
- Electrical System
- Propulsion Systems
- Cabin Management Services
- Flight Recorder System

2.1.2.2. Information Services Domain

The Information Services Domain (ISD) provides services and connectivity between independent aircraft domains such as avionics, in-flight entertainment, cabin distribution and any connected off-board networks. The ISD provides a security perimeter, incorporating network routing and security functions/services between ISD and less critical domains and any connected wireless networks.

The ISD must protect itself from other domains and networks. The ISD provides general purpose routing, computing, data storage and communications services for non-essential applications.

The ISD may be comprised of one or more computing platforms for third party applications and content.

ISD platforms may be used to support applications and content for either cabin or flight crew use. The physical configuration of the ISD network on a given aircraft may vary based on network segregation, off-aircraft connectivity and airline functional requirements. Airline and airframe-defined operational requirements for functional availability will determine equipment and service redundancy requirements within the ISD.

Given that the ISD architecture may vary between aircraft types and airline operational requirements, the ISD must be defined based on open computing and commercial networking definitions to standardize its network environment. The ISD provides shared network services and resources for use by other subsystems. Common network services and network management are required to enable use of common applications across mixed aircraft fleets. ISD platforms may support applications that interface with avionics systems. Avionics systems may access mass storage devices in the ISD. ISD hosted applications may have communications with avionics systems. ISD platforms should support the distribution and storage of specified avionics data. Typical examples of ISD avionics interface applications include data Loader services, Virtual Quick Access Recorder (VQAR) and central maintenance functions.

When a dedicated off-board network connection for passenger use is connected to and managed within the ISD, the ISD should provide central security and routing services to transparently support multiple aircraft-ground connections.

ISD external network connection requirements include network resources and services shared by connected subsystems. The ISD external network may be shared as a possible path for off-board passenger communications/data transfer (pass-through). As such, the ISD should be capable of prioritizing network traffic. ISD off-board network connectivity should provide a common application interface and transparent message routing via one or more wireless solutions. Examples of ISD services include:

- Airborne Data Loader
- Maintenance Access
- Cabin Crew Information Access
- Network Management Facility
- Network Operation Services (DNS, DHCP, VPN, etc.)
- Network File/Print Services

2.1.2.3. In-Flight Entertainment Domain

This domain is characterized by the need to provide passenger entertainment and network services. An analogy used many times is that the airline passenger should be able to enjoy the same services as being in a hotel room. The functionality of this domain is the most dynamic in that IFE systems are typically replaced frequently. Also, the technology available to the passenger changes regularly. The passenger can be expected to carry onboard increasingly sophisticated devices that in the passenger's mind should work as well on the aircraft as they would in the hotel room. Passenger applications provided by the IFE system may include:

- Streaming Video
- Streaming Audio
- Passenger Internet surfing
- Moving maps (PFIS)
- Voice over IP (VoIP)
- Gaming
- SMS (Short Message Service)

2.1.2.4. Passenger Personal Electronic Devices (PED) Domain

The avionics and information services domains may also provide services and connectivity between independent aircraft domains such as in-flight entertainment, cabin distribution and any connected off-board networks. The ISD provides a security perimeter, incorporating network routing and security functions/services between ISD and less critical aircraft domains and any connected wireless networks. Applications and devices carried on board by passengers are limitless. These applications may be both benign and malicious.

2.1.3. CNS Integrated Architecture Approaches

Figure 2.6 presents the high-level block diagram of the communication, navigation and surveillance functions. In general each of them can be thought of as consisting of a transport mechanism to transfer data, a set of applications, and a set of displays to present the received data. There are a number of ways to integrate the CNS functions using an integrated architecture. Two possible approaches are indicated by the dotted line.

In the first approach called vertical integration, all the communication functions are integrated into a single integrated architecture. Similarly the navigation and surveillance function are also integrated into an integrated architecture.

In the second approached called horizontal integration, similar function from communications, navigation and surveillance are combined to form an integrated architecture. This is indicated by the white dotted lines. In this approach all the display functions are combined to form a integrated display function. The interesting architectural integration is the integrated architecture at the radio level. This approach is similar to the software defined radio technique.

2.1.4. Trends in Near Term Avionics Architecture

The Multi-Mode Receiver (MMR) and ARINC 750 are examples of existing standards that imply a certain level of integration in implementation. The ARINC 750 radio must be able to handle 25 KHz and 8.33 KHz amplitude modulated voice, ACARS using 2400 BPS Minimum-Shift Keying (MSK) data, and VDL Mode 2 using differential 8-phase shift keying (D8PSK) at 31.5 Kbps. Since the industry is considering at least two other possible additions to the

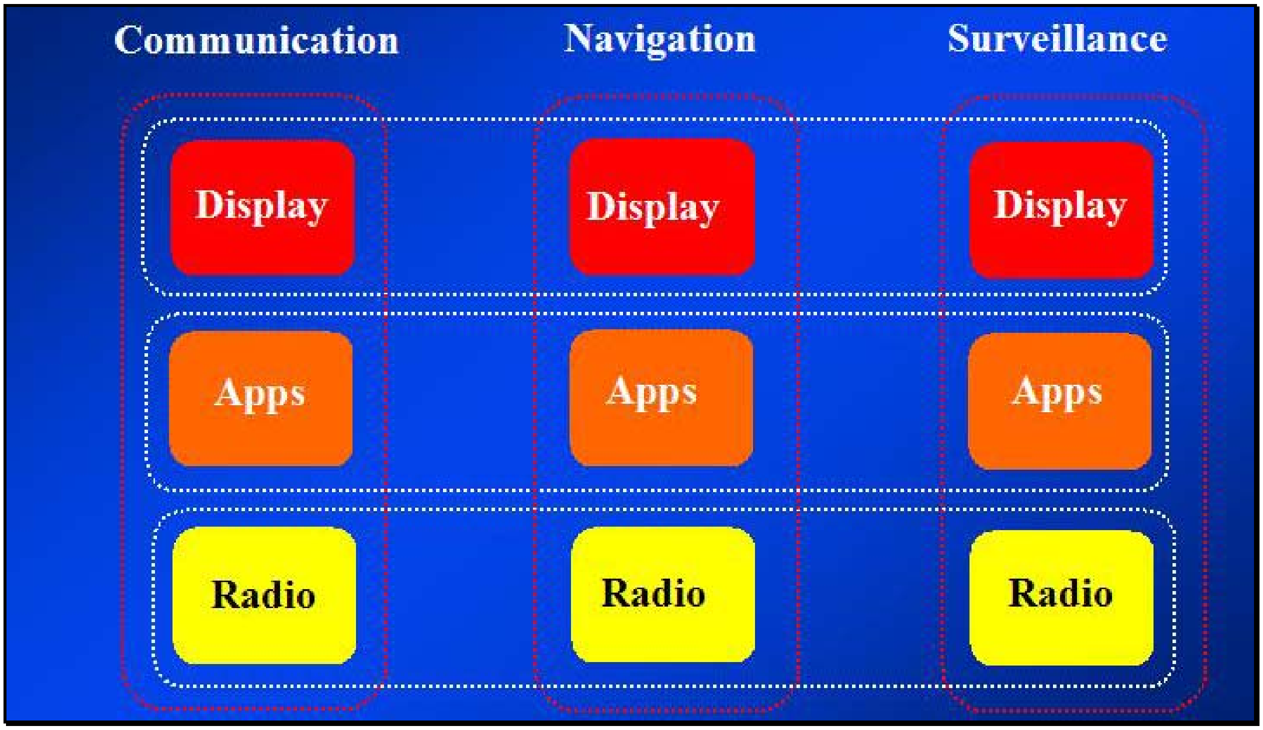

Figure 2-6. CNS Integration Architectural Approaches

capabilities of this radio, it might seem prudent to implement it in a manner that does not require installation of four, five or six different analog receivers.

With modern digital signal processors and miniaturized RF components, one can imagine a hardware platform that could accommodate the four radio requirements of ARINC 750. This commercial airborne VHF radio has the distinct advantages of only being required to implement one communication method at a time in the aeronautical communications VHF band (i.e., 117.975 to 137 MHz). Certainly, the full-blown architecture of JTRS is not needed in order to implement ARINC 750. However, considering a flexible, expandable architecture, such as the one defined at the top-level for JTRS, could make for an implementation that may not need to be completely redone when the next mode comes along.

2.1.4.1. ARINC 755-2 Multi-Mode Receiver (MMR)

This standard describes the characteristics of a radio/processor capable of receiving Instrument Landing System (ILS), Microwave Landing System (MLS) and Global Navigation Satellite System (GNSS) source inputs. The desired operational capability of the equipment, standards necessary to ensure interchangeability, form factor, and pin assignments are included. The MMR provides flight path deviation guidance to the aircraft during the final approach and landing phases of flight.

2.1.4.2. ARINC 750-3 VHF Data Radio (VDR)

This standard specifies the form, fit and functional definitions for a VHF transceiver capable of voice and data communications. The VHF transceiver supports, 8.33 KHz AM and 25 KHz AM voice, and VHF Digital Link Mode 2 (VDL-2) data link communications as defined by ICAO. ARINC 631 is a companion standard.

2.1.5. Software Defined Radios

The military communication initiative called the Joint Tactical Radio System (JTRS) deals with many, varied, communications links and protocols. It also deals with a wide variety of frequency and antenna requirements and an ever more complex implementations. It is not unlike having to define a Multi-Mode Receiver for various navigation and landing aids in commercial aviation. It is also not unlike finding irreconcilable antenna/interference issues among the competing methods for next generation aeronautical VHF digital link.

However, there are some valuable lessons to be learned in how the military is going about reconciling what appears to be irreconcilable problems by defining an architecture that considers hardware as well as software issues in a coherent manner.

2.1.5.1. Software Defined Radio Background

The Software Defined Radio (SDR) concept started in the late 1970s with the introduction of multimode radios operating in VHF band. The U.S. Air Force Avionics Laboratory initiated the Integrated Communication, Navigation, Identification and Avionics (ICNIA) program in the late 1970s. This program developed an architecture to support multifunction, multi-band airborne radios in the 30 MHz – 1600 MHz band that was successfully flight tested. A final report was delivered in 1992. The ICNIA radio was the first programmable radio. Then in the late 1980s, the Air Force Research Laboratory initiated the Tactical Anti-Jam Programmable Signal Processor (TAJPSP) and developed a processor capable of simultaneous waveform operations using a modular approach.

Then the Department of Defense (DoD) began the development of SDR technology through the SPEAKeasy research program in 1992. The objectives of the program were to consolidate a family of discrete military radios into a single platform using software radio technology. The SPEAKeasy program yielded significant advancements for SDRs. The program proved the feasibility of SDR technology, achieved a significant reduction in the size and weight of SDR devices, and increased both computational capacity and overall system performance.

Then the U.S. Government invited industry to participate in the Modular Multifunction Information Transfer Systems (MMITS) forum. This forum initially functioned as a guiding body for the establishment of open architecture standards for the SPEAKeasy program. The MMITS forum eventually shifted its focus from the government community to the commercial community. In 1999, the MMITS forum officially changed its name to the SDR Forum. Since then, the SDR Forum has promoted SDR technologies with applications for commercial cellular, Personal Communication Systems (PCS), and emerging third-generation (3G) and fourth-generation (4G) cellular services.

The JTRS Joint Program Office (JPO) was established in 1999. The JTR is envisioned to be the next generation tactical radio for future advanced military operations. The mission of the JPO is to "acquire a family of affordable, high-capacity tactical radios to provide interoperable LOS/BLOS C4I capabilities to the war fighters".

2.1.5.2. SDR Evolution in Europe

R&D in Advanced Communications in Europe (RACE), Advanced Communications Technology and Services (ACTS) programs – ACTS projects, Flexible Integrated Radio System and Technology (FIRST) and Future Radio Wideband Multiple Access System (FRAMES) used software radios to investigate next-generation air-interfaces. The RACE and ACTS focused on incorporating 3G and potentially 4G standards into Global System for Mobile (GSM) communications network. This paved the way for more capable and more powerful products and flexible services. The key research areas included receiver architecture, baseband Digital Signal Processor (DSP) architecture, and enabling technologies.

2.1.5.3. SDR Evolution in ASIA

The Japanese Institute of Electronics, Information and Communication Engineers (IEICE) software radio group was formed in 1999. It held technical conferences, workshops, panel discussions and symposia, in conjunction with the SDR Forum Radio. The Korea Electromagnetic Engineering Society (KEES) sponsored a workshop in 2000 to monitor software radio activities in Korea, Japan and Taiwan. The IEICE and KEES missions are to promote R&D in SDR, allow protocol, software, and hardware to be easily integrated for future radio systems, foster cross-organization and collaboration among academia, industries and governments and organize symposia and workshops on SDR.

2.1.5.4. SDR for A/G Communications

SDR can provide potential benefits for the aviation community by:

- Accommodating multiple air-interface standards
- Facilitating transition by bridging legacy and future technologies
- Allowing multiple services – incentives for equipage
- Implementing "future-proof" concepts – capable for insertions of future technologies
- Allowing easy upgrades
- Implementing open-architecture to allow multiple vendors to supply or participate
- Offering declining prices
- Reducing product development time
- Enabling other advanced commercial technologies to be adapted to offer user's services and benefits

2.1.5.5. Software Defined Radio Technology

The SDR Forum defines the ultimate software radio as one that accepts fully programmable traffic and control information and supports a broad range of frequencies, air-interfaces, and applications software. The user can switch from one air-interface format to another in milliseconds. The exact definition of a software radio is controversial, and no consensus exists about the level of reconfigurability needed to qualify a radio as a software radio. A radio that includes a microprocessor or digital signal processor does not necessarily qualify as a software radio. However, a radio that defines in software its modulation, error correction, and encryption processes, exhibits some control over the RF hardware, and can be reprogrammed is clearly a software radio.

A good working definition of a software radio is “a radio that is substantially defined in software and whose physical layer behavior can be significantly altered through changes to its software”. The degree of reconfigurability is largely determined by a complex interaction between a numbers of common issues in radio design, including systems engineering, antenna form factors, RF electronics, base band processing, speed and reconfigurability of the hardware, and power supply management.

The term software radio generally refers to a radio that derives its flexibility through software while using a static hardware platform. On the other hand, a “soft radio” denotes a completely configurable radio that can be programmed in software to reconfigure the physical hardware. In other words, the same piece of hardware can be modified to perform different functions at different times, allowing the hardware to be specifically tailored to the application at hand. Nonetheless, the term software radio is sometimes used to encompass soft radios as well.

The functionality of conventional radio architectures is usually determined by the hardware with minimal configurability through software. The hardware consists of the amplifiers, filters, mixers (probably several stages), and oscillators. The software is confined to controlling the interface with the network, stripping the headers and error correction codes from the data packets, and determining where the data packets need to be routed based on the header information. Because the hardware dominates the design, upgrading a conventional radio design essentially means completely abandoning the old design and starting over again. In upgrading a software radio design, the vast majority of the new content is software and the rest is improvements in hardware component design. In short, software radios represent a paradigm shift from fixed, hardware-intensive radios to multi-band, multimode, software-intensive radios.

For SDR to work to its full potential and offer truly interoperable radios, the underlying software architecture must offer a development framework that segregates the RF, digital signal processing hardware and software, and provide a mechanism to tie them all together. The architecture should also be open source to avoid incompatible proprietary solutions. The Software Communications Architecture (SCA) is such an architecture. The SCA is a set of specifications describing the interaction between the different software and hardware components of a radio and providing software commands for their control.

In addition, interoperability is supported through the use of software-based waveforms. The waveform software developed for JTRS includes not only the actual radio frequency (RF) signal in space, but also the entire set of radio functions that occur from the user input to the RF output and vice versa. For example, in the transmitting JTRS, the waveform software will control the receipt of the data (either analog or digital) from the input device and manage the encoding. The encoded data is passed to the encryption engine. The resultant encoded/encrypted data stream is modulated into an intermediate frequency (IF) signal. Finally, the IF signal is converted into a RF signal and transmitted to the antenna. These same functions will be reversed in the receiving JTRS with the ultimate output of the data to the user.

Waveform portability is an important characteristic of SDR. Waveform portability means the basic waveform software is developed in such a way that it may be "ported" to multiple hardware platforms and operating systems. Portability is an underlying tenet of the JTRS and its development based on SCA. This reduces the cost associated with development of JTRS, since each waveform is built only once. It also increases the potential for interoperability among JTRS hardware.

2.1.5.6. Characteristics and Benefits of a Software Radio

Implementation of the ideal software radio would require either the digitization at the antenna, allowing complete flexibility in the digital domain, or the design of a completely flexible radio frequency (RF) front-end for handling a wide range of carrier frequencies and modulation formats. The ideal software radio, however, is not yet fully exploited in commercial systems due to technology limitations and cost considerations.

A model of a practical software radio is shown in Figure 2-7. The receiver begins with a smart antenna that provides a gain versus direction characteristic to minimize interference, multipath, and noise. The smart antenna provides similar benefits for the transmitter.

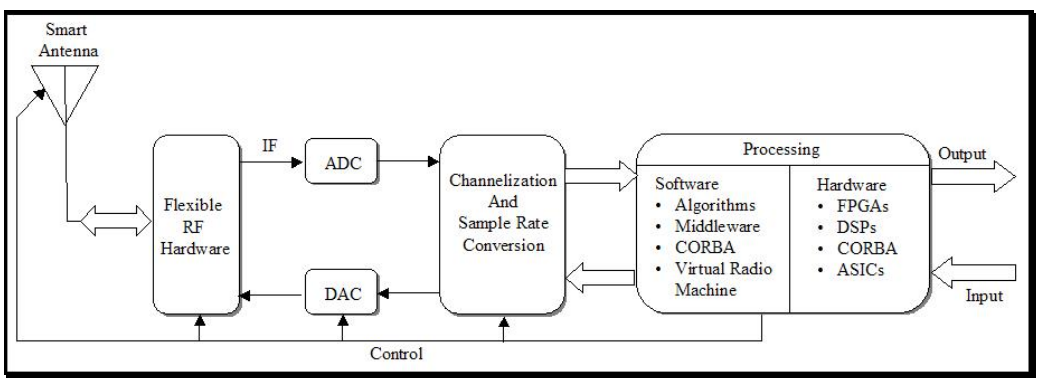

Figure 2-7. A Software Defined Radio (SDR) Model

Most practical software radios digitize the signal as early as possible in the receiver chain while keeping the signal in the digital domain and converting to the analog domain as late as possible for the transmitter using a Digital to Analog Converter (DAC). Often the received signal is digitized in the Intermediate Frequency (IF) band. Conventional radio architectures employ a super heterodyne receiver, in which the RF signal is picked up by the antenna along with other spurious/unwanted signals, filtered, amplified with a Low Noise Amplifier (LNA), and mixed with a Local Oscillator (LO) to an IF.

Depending on the application, the number of stages of this operation may vary. Finally, the IF is mixed exactly to baseband. Digitizing the signal with an Analog to Digital Converter (ADC) in the IF range eliminates the last stage in the conventional model in which problems like carrier offset and imaging are encountered. When sampled, digital IF signals give spectral replicas that can be placed accurately near the baseband frequency, allowing frequency translation and digitization to be carried out simultaneously. Digital filtering (channelization) and sample rate conversion are often needed to interface the output of the ADC to the processing hardware to implement the receiver. Likewise, digital filtering and sample rate conversion are often necessary to interface the digital hardware that creates the modulated waveforms to the digital to analog converter. Processing is performed in software using DSPs, field programmable gate arrays (FPGAs), or application specific integrated circuits (ASICs).

The algorithm used to modulate and demodulate the signal may use a variety of software methodologies (such as middleware) or virtual radio machines, which are similar in function to JAVA virtual machines. [Common Object Request Broker Architecture (CORBA) is an example of middleware.] This forms a typical model of a software radio.

The software radio provides a flexible radio architecture that allows changing the radio personality, possibly in real-time, and in the process somewhat guarantees a desired Quality of Service (QoS). The flexibility in the architecture allows service providers to upgrade the infrastructure and market new services quickly. This flexibility in hardware architecture combined with flexibility in software architecture (through the implementation of techniques such as object oriented programming and object brokers) provides the software radio with the ability to seamlessly integrate itself into multiple networks with wildly different air and data interfaces. In addition, a software radio architecture gives the system new capabilities that are easily implemented with software. For example, typical upgrades may include interference rejection techniques, encryption, voice recognition and compression, software-enabled power minimization and control, different addressing protocols, and advanced error recovery schemes.

2.1.5.7. Software Defined Radio Architecture

The generic SDR architecture comprises specific functional blocks connected via open interface standards. The SDR architecture supports three specific domains: hand-held, mobile, and base-station (or fixed site). Figure 2-8 illustrates a high-level hierarchical functional model for a two-way (send and receive) SDR device.

Three views of increasing complexity are presented. The top-level view is a simple representation of an entire information transfer thread. The left side interface is the air interface. The right side interface is the user interface.

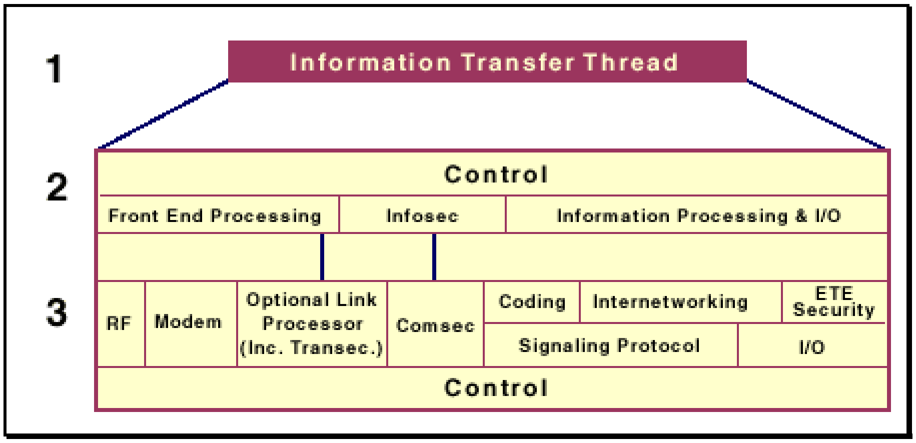

Figure 2-8. Hierarchical Functional Model of SDR

The next level view identifies a fundamental ordered functional flow of four significant and necessary functional areas:

- Front end processing
- Information security
- Information processing
- Control

Front end processing consists of the physical air (or propagation medium) interface, the front-end radio frequency processing, and any frequency up and down conversion. Also, modulation and demodulation processing is contained in this functional block area.

Information Security (INFOSEC) provides user privacy, authentication, and information protection. In the military and public safety communities, INFOSEC for sensitive and classified communications must be consistent with the government security policies as defined by the NSA.

Content or information processing is the decomposition or recovery of the embedded information containing data, control, and timing. Content processing and Input/Output (I/O) functions map into path selection (including bridging, routing, and gateway), multiplexing, source coding (including vocoding, and video compression/expansion), signaling protocol, and I/O functions.

The functional components of SDR architecture are connected together via open interfaces. Each functional component in the SDR architecture is controlled with software. The software necessary to operate an SDR device is called a software application. Figure 2-9 illustrates the SDRF (Software Defined Radio Forum) open architecture comprising of seven independent subsystems interconnected by open interfaces. Interfaces exist for linking software application specific modules into each subsystem. Each subsystem contains hardware, firmware, an operating system, and software modules that may be common to more than one application.

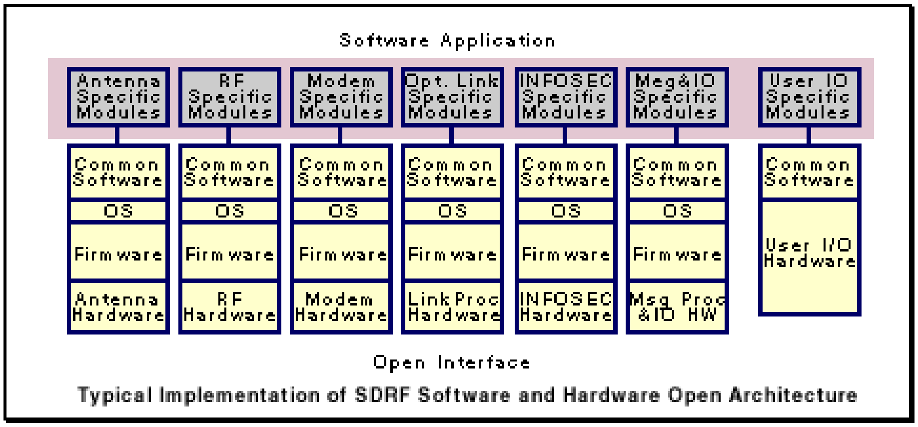

Figure 2-9. Generic Software Subsystem SDR Model

The application layer is modular, flexible, and software specific. The common software Application Programming Interface (API) layer is typically standardized with common functions based on defined interfaces.

2.1.5.8. SDR Functional Perspective

Figure 2-10 illustrates the SDRF functional interface diagram and demonstrates how the SDRF architecture provides definition to the functional interfaces. A representative information flow format is provided at the top of the diagram. For example, information transfer is effected throughout the functional flow within the SDRF architecture to/from antenna-RF, RF-modem, modem-INFOSEC, and INFOSEC-Message Processing interfaces. The specific implementation would determine the actual control and status between the interfaces and functional module.

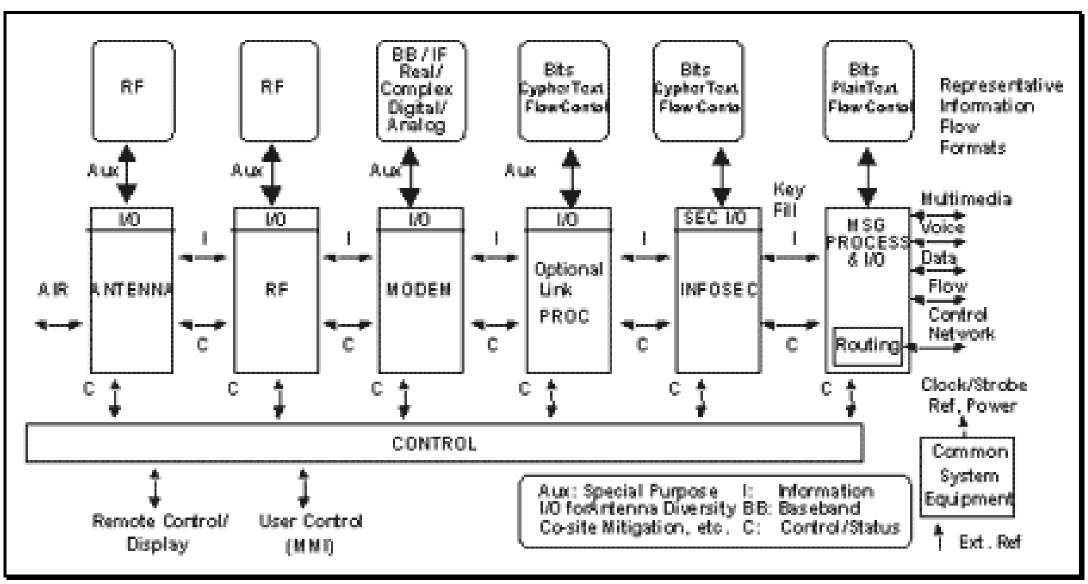

Figure 2-10. Functional Subsystem SDR Model

The actual information being transmitted by an SDR device follows the paths illustrated by the "I" within Figure 2-10. The SDR device operates by providing control ("C") messages through each of the functional blocks as indicated by the control function. As an example, the frequency at which a wireless signal is generated is determined by frequency generation in the RF function. Through the control capability, an SDR device would allow this frequency to be changed to accommodate different operating environments (useful in situations where users move between systems with different operating frequencies).

An example SDR implementation for a piece of subscriber equipment may be viewed in comparison with a generic PC model in the form of a multiple service model as illustrated below in Figure 2-11.

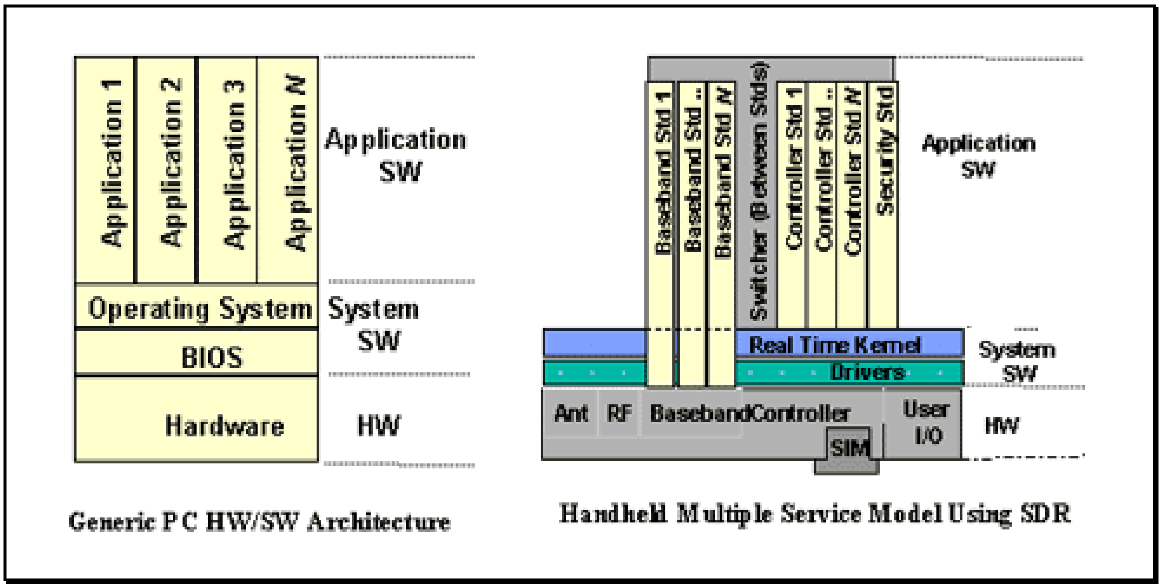

Figure 2-11. Functional Software Subsystem SDR Model

The specific implementations for each service (e.g., different air interface technologies in communication systems) are shown to be included through the system software layer and directly interfacing the hardware layer. The most common factors considered in SDR subscriber equipment development are based upon the following: battery power, size, weight, and specific user and cost requirements. In order to achieve processing speed and efficiency, the majority of implementations are programmed very close to the underlying hardware or logic, using low-level languages such as assembly language. The task of switching between multiple operating bands using the same or different RF hardware is managed by a combination of the service switcher and the controller services for each individual operational mode.

2.1.6. Relationship Between Avionics Architecture and Aircraft Types

The avionics functional architecture includes functions that are applicable to a wide range of aircraft classes including commercial carrier and cargo transport aircraft, business jets, general aviation, and military aircraft.

In general, the aircraft equipage is a function of a number of parameters. The major factors that affect the equipage are:

- Type of airspace
- Safety requirements
- Security requirements
- Power requirements
- Weight requirements

In addition, military aircraft may have other requirements such as electronic warfare. In this section, the avionics architecture is addressed using airspace as the frame of reference. The two categories of airspace are: regulatory and non-regulatory. Within these two categories there are four types: controlled, uncontrolled, special use, and other airspace. Further information can be found in the Aeronautical Information Manual. Figure 2-12 presents a profile view of the dimensions of various classes of airspace. Table 2-1 lists the operational and equipment requirements by class of airspace.

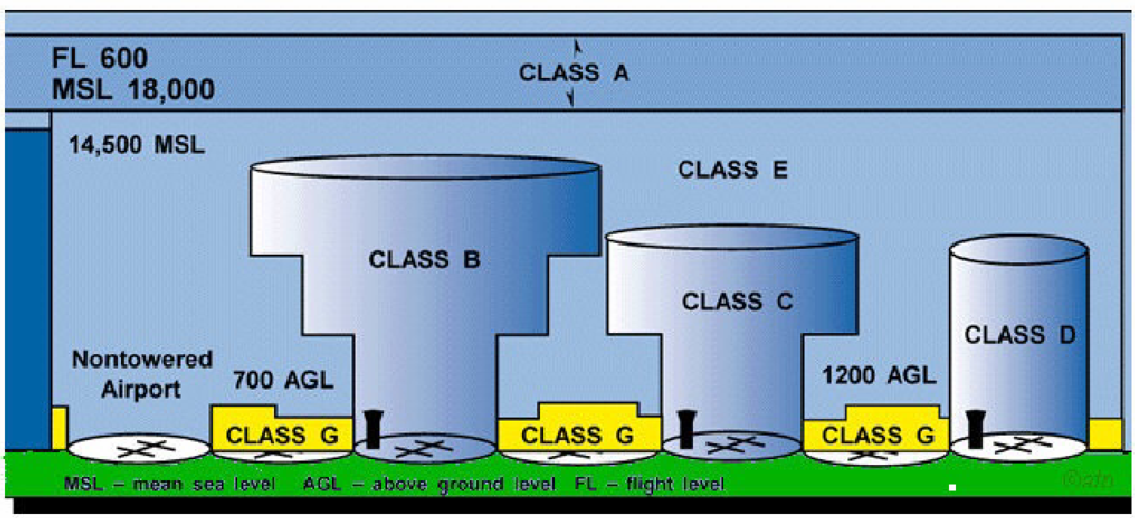

Figure 2-12. Airspace Classification

2.1.6.1. Controlled Airspace

Controlled airspace is a generic term that covers the different classifications of airspace and defined dimensions within which air traffic control service is provided in accordance with the airspace classification. There are five classes of controlled airspace - Class A through Class E.

Table 2-1. Airspace Operational and Equipment Requirements

Class Airspace	Entry Requirements	Equipment
A	ATC Clearance	IFR Equipped
B	ATC Clearance	Two-Way Radio Transponder with Altitude Reporting Capability
C	Two-way Radio Communications Prior to Entry	Two-Way Radio Transponder with Altitude Reporting Capability
D	Two-way Radio Communications Prior to Entry	Two-Way Radio
E	None for VFR	No Specific Requirements
G	None	No Specific Requirements

2.1.6.1.1. Class A Airspace

Class A airspace is generally the airspace from 18,000 feet Mean Sea Level (MSL) up to and including FL600. It includes the airspace overlying the waters within 12 nautical miles (nm) of the coast of the 48 contiguous United States and Alaska. Unless otherwise authorized, all operation in Class A airspace will be conducted under instrument flight rules (IFR).

2.1.6.1.2. Class B Airspace

Class B airspace is generally the airspace from the surface to 10,000 feet MSL surrounding the nation’s busiest airports. The configuration of Class B airspace is individually tailored to the needs of a particular area and consists of a surface area and two or more layers. Some Class B airspace resembles an upside-down wedding cake. At least a private pilot certificate is required to operate in Class B airspace. However, there is an exception to this requirement. Student pilots or recreational pilots seeking private pilot certification may operate in the airspace and land at other than specified primary airports within the airspace if they have received training and had their logbook endorsed by a certified flight instructor in accordance with 14 CFR part 61.

2.1.6.1.3. Class C Airspace

Class C airspace generally extends from the surface to 4,000 feet above the airport elevation surrounding those airports having an operational control tower, which are serviced by a radar approach control. There is also a requirement for a certain number of IFR operations or passenger emplacements. This airspace is charted in feet MSL, and is generally of a 5 nm radius surface area that extends from the surface to 4,000 feet above the airport elevation, and a 10 nm radius area that extends from 1,200 feet to 4,000 feet above the airport elevation.

There is also an outer area with a 20 nm radius that extends from the surface to 4,000 feet above the primary airport and this area may include one or more satellite airports.

2.1.6.1.4. Class D Airspace

Class D airspace generally extends from the surface to 2,500 feet above the airport elevation surrounding those airports that have an operational control tower. The configuration of Class D airspace will be tailored to meet the operational needs of the area.

2.1.6.1.5. Class E Airspace

Class E airspace is generally controlled airspace that is not designated A, B, C, or D. Except for 18,000 feet MSL, Class E airspace has no defined vertical limit, but rather it extends upward from either the surface or a designated altitude to the overlying or adjacent controlled airspace.

2.1.6.2. Uncontrolled Airspace - Class G Airspace

Uncontrolled airspace or Class G airspace is the portion of the airspace that has not been designated as Class A, B, C, D, or E. It is therefore designated uncontrolled airspace. Class G airspace extends from the surface to the base of the overlying Class E airspace. Although air traffic control (ATC) has no authority or responsibility to control air traffic, pilots should remember there are VFR minimums that apply to Class G airspace.

Based on the above information, the commercial carrier aircraft may carry equipment related to communication, navigation and surveillance. The number of radios of each type is a function of other requirements such as weight, power, safety, security and regulations.

The military aircraft may have equipage similar to that of a commercial carrier but may differ in the level of sophistication and capability. Weight and security requirements may play a significant role in this environment.

Cargo transport aircraft may be classified as falling under the commercial carrier market segment. Therefore, equipage on a cargo transport aircraft may be similar to the commercial air carrier aircraft. Again, the main difference may be the quantity of avionics.

Business jets can be considered a more sophisticated version of the commercial carrier aircraft with enhanced and additional capabilities. Therefore, their avionics capabilities are enhanced version of the carrier aircraft.

General aviation equipage configuration may vary depending on the class of airspace in which they fly. General aviation aircraft flying in class B airspace may be equipped with at least some type communication and surveillance equipment. In addition, they may have navigation equipment. General aviation aircraft flying in class E airspace has no specific requirement. In general, about 80 percent of general aviation aircraft carry communications, navigation and surveillance equipment.

2.2. Task 3 – Product and Architectural Survey

2.2.1. Survey Summary

A survey was conducted to determine relevant architectures, products and approaches that may influence the design of MMDA. The data collected spans both military and commercial software defined radio development. Table 2-2 lists all of the applicable systems where relevant architecture data was gathered and analyzed.

Two major factors were considered in selecting systems for analysis and applicability. First, the systems needed to be multi-band communications systems. Products that had multiple modes or voice and data under a small frequency band, such as Link 16, provide some useful data but do not address the critical requirements of simultaneous operations of multiple waveforms over a wide band of frequencies. Second, systems that were not airborne in nature were not considered with the exception of the JTRS waveforms. These systems although they maybe interesting in their design approach, process and outcome do not have the difficult flight certification requirements (with the exception of ground air traffic control stations) imposed on them. Therefore, much of the software design is not held to the same standards as avionics systems.

Because the use of SCA and CORBA have been a recent technological insertion in the marketplace, not all of the systems analyzed and reviewed meet this requirement. Three of the earliest efforts to develop integrated communication were undertaken well before many of the software standards were developed and imposed. These systems, however, do provide valuable lessons learned in dealing with both software and hardware aspects of multi-function, multi-band communications systems.

2.2.2. Architectural Experience Leading to MMDA

A Multi-function Multi-mode Digital Avionics software defined radio may attain a good portion of its legacy from past military programs, whose basic objective was a higher level of integration of communications functions into a common radio design. The history of these programs provides two important elements for the MMDA effort. First, these historical architectures provide numerous lessons learned that can be applied to the final MMDA architecture. Second, key elements of the application of the Software Communications Architecture (SCA) embedded with the Common Object Request Broker Architecture (CORBA) have been addressed for avionics applications.

Integrated communications, navigation and identification (surveillance) systems have been under development for use on military aircraft since the early 1980s. The majority of this development work was conducted at TRW (now Northrop Grumman) in San Diego, California, beginning with the Integrated Communications Navigation Identification Avionics (ICNIA) program in 1983. Development continued through the years with the F-22 Communications, Navigation, Identification (CNI) program, the RAH-66 Comanche Helicopter CNI program, and today with the Joint Strike Fighter F-35 CNI program. The efforts also included major design participation by Rockwell Collins in Cedar Rapids, Iowa, and Singer Kearfott (now British Aerospace Enterprises) and ITT in Nutley, New Jersey. These four major development programs represent a government investment of nearly $2 billion.

Table 2-2. Pertinent Programs

Program	Participating Companies	Application	Dates	JTRS or SCA Compatibility
ICNIA	TRW Rockwell Collins Singer Kearfott	Military	1983 – 1989	No
YF-22 DEM/VAL	Lockheed Martin TRW Rockwell Collins GEC Marconi	Military	1988 – 1990	No
F-22 CNI	Lockheed Martin TRW Rockwell Collins BAE Harris ITT Avionics	Military	1991 – 2001	No
RAH-66 Comanche CNI	Boeing TRW Rockwell Collins BAE	Military	1996 – 2004	Partial
F-35 CNI	Lockheed Martin Northrop Grumman Rockwell Collins	Military	2002 – 2012	Partial
Modular Digital Radio	General Dynamics	Military	1996 – 2004	Partial
Software Defined Radio	Mitre	Commercial	on-going	Yes
JTRS/SCA	Rockwell Collins	Commercial	on-going	Yes
JTRS	Various	Military	on-going	Yes
NEXCOM VDL Modes 2, 3	ITT	Commercial	on-going	Partial
AN/ARC-210	Rockwell Collins	Military	on-going	No
VDL 2000	Rockwell Collins	Commercial	on-going	No
NEXCOM UHF	General Dynamics	Commercial	on-going	Partial
NEXCOM Ground System	Harris	Commercial	on-going	Partial
Software Radio 3.3	Australian Telecommunications	Commercial	1999 – 2001	No

Program	Participating Companies	Application	Dates	JTRS or SCA Compatibility
Radio Description Language of SCA	Vanu Inc	Military	2002	Yes
US Navy Speakeasy	ITT	Military	1992 – 1998	No
ARINC 750 VDL/CMU	Honeywell TRW	Commercial	1998 – 2000	No

The Department of Defense led by the US Army has also invested billions of dollars to update all communications systems for future interoperability. Today with the proliferation of waveforms and significantly different radio designs, many combat scenarios can be stifled by a lack of radio interoperability. The Joint Tactical Radio System is the DoD approach to guarantee the interoperability of future system by building open architecture hardware radios with SCA compliant software. The functions will be designed with well-defined interfaces and performance requirements to allow the waveforms to be used at a consistent performance level on a compliant radio. The US government will retain the right of ownership of the individual waveforms, eliminating the possibility of contractors making adjustments that alter the performance or approach, and giving them a proprietary design. An objective of the JTRS program is to develop an open architecture and cost competition in developing the radios.

A key design within the JTRS program is a compliant Link-16 radio system. Link 16 is the heart of the current military data link structure. This is a key element for the government to achieve because all tactical aircraft will require Link 16 capability in order to be a part of master controlled digital battlefield environment. The concentration of the JTRS program up to this point has been on continuous wave/voice type waveforms. Some of these waveforms (like Link 4, Link 11 and Link 22) carry digital data. However, the primary focus has been on a lower frequency voice capability in the UHF/VHF band. Link 16 JTRS departs from this with L Band and pulse waveforms. It should also be noted Link 16 JTRS will be a four acquisition channel radio with similar requirements and considerations for voice and data Time Division Multiple Access (TDMA) channels, as will be examined for the MMDA approach.

2.2.3. Integrated Communications Navigation Identification Avionics (ICNIA)

The US Air Force at Wright Paterson Air Force Base sponsored the ICNIA program beginning in 1983. It was a brass board demonstration effort designed to initially prove the feasibility of integrating communications functions using common hardware and software. Demonstrations included real time, re-assignable, assets, simultaneously operating functions on reconfigurable hardware. Implementation of the design would cut the size and weight by 50% compared to a set of legacy, federated radios. This first effort was a more hardware intensive approach for waveform demodulation and primary signal processor algorithms. Further improvements were to be achieved with extensive built in test and the use of advanced components configured in a modular architecture and hardware.

The implementation of the architecture is illustrated in Figure 2-13. The three key pieces of common hardware include a set of multi-band receivers designed for operations of HF, VHF, UHF and L Band signals. On the digital side of the architecture, a Universal Match Filter (UMF) provides a signal-processing capability that can be reconfigured to accommodate any one of the specified CNI waveforms.

On the transmit side waveforms were generated by two common exciter/synthesizer assemblies capable of generating either pulse or continuous waveforms. The final stages of power amplification were generated using unique carrier generators plus VHF/UHF and L Band power amplifiers.

Although the system was based on common hardware assemblies, custom control and data buses were used throughout the system. These were not open architecture in nature and used a custom data structure between the RF front end and the signal and data processing assets. One drawback to this bus structure was a failure to provide optimal performance when module slots were unoccupied, that is when a slot is unoccupied the bus had difficulty initiating.

The centerpiece of the digital design in the system was the use of two types of highly integrated technology. First, the implementation of Very High Speed Integrated Circuits (VHSIC) and second the use of Application Specific Integrated Circuits (ASIC). Both of these devices were for their time densely packed digital circuits that significantly reduced size and improved performance.

The software architecture was based on a modularity concept that maximizes software reusability with a goal of 100% reuse. Resource management software was designed to support hardware resource sharing. Software reconfiguration provided fault tolerance for hardware failures. Additionally, integrated test and maintenance software provided real time fault detection and isolation for maintenance and logistics support. The overall design maximized the use of existing software resources to minimize cost and risk. This included GPS and executive software, JTIDS and integrated navigation solutions. Software was designed using various tools in both military and commercial techniques. These tools included GFE 1750A/J73, TRW Ada PDL and Signal processor development tools and S.K. Translators. Since software was hosted directly on the processor hardware, various languages from Jovial to C to Ada were implemented. The software design did not focus on common algorithms or processing techniques. The implementation goal was to demonstrate the capability to perform functions.

There were three core processor groups that formed the core of the programmable resources as illustrated in Figure 2-14. Higher-level signal processing and message control processing were performed by special VHSIC signal processing and 1750A data processing respectively. The key feature of the software architecture centers on multiple independent processors with identical software loads. The ICNIA program was one of the first attempts by the US Air Force to extensively use Built-in-Test (BIT) in a computer-based, software based design. BIT was performed on individual resources as well as strings (multiple) resources. All BIT was performed using high-speed control buses and also a module maintenance bus.

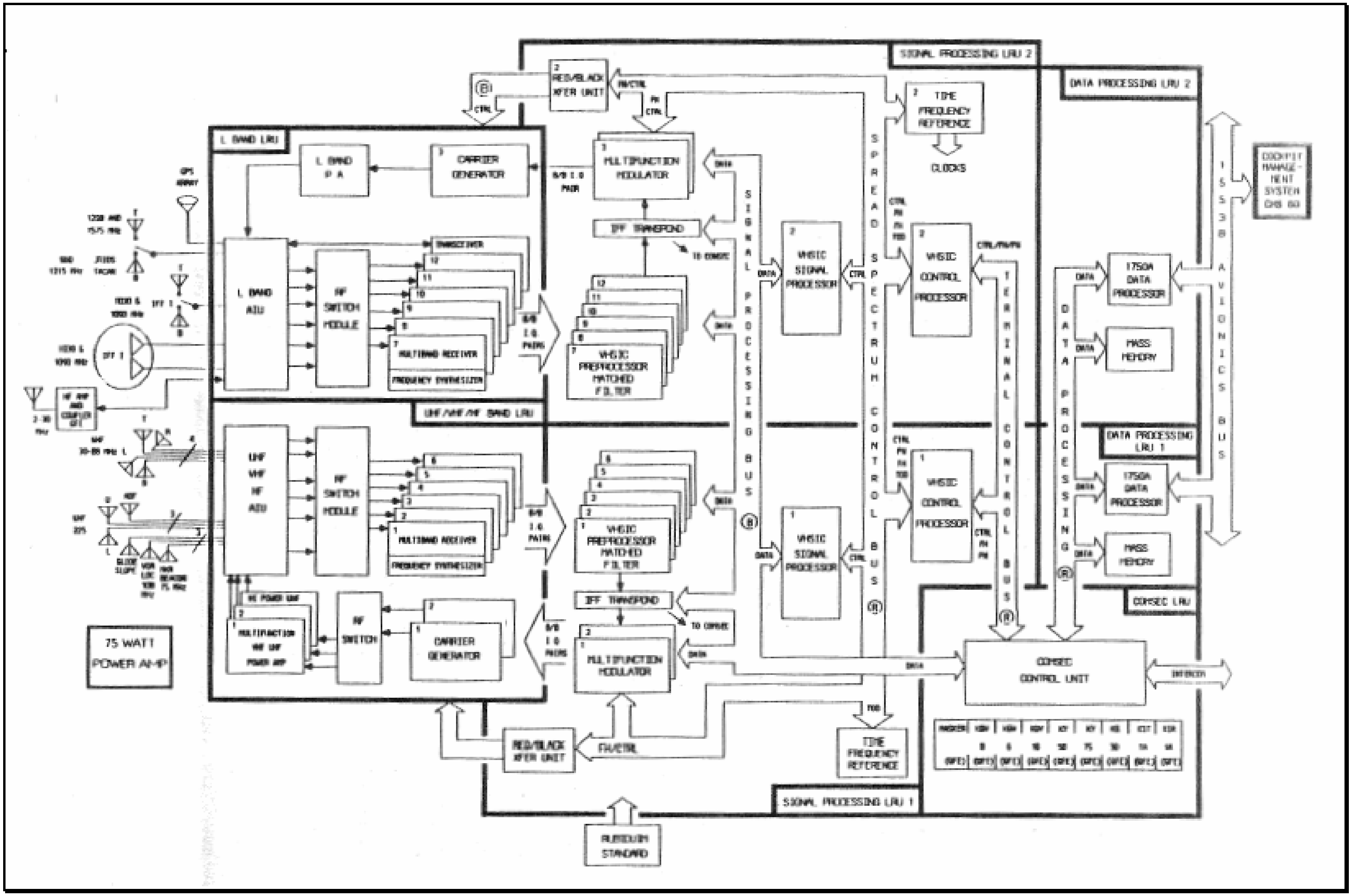

Figure 2-13. ICNIA Advanced Development Model Architecture

The advantage to the ICNIA system architecture was the use of multiple, redundant types of BIT. Startup BIT was used to establish the initial health of the CNI system. Additionally, BIT can be performed on-line in a non-interference fashion with CNI functions. This is accomplished in a continuous manner during operations. Off-line BIT can also be performed during operational run-time. However, it precludes the operation of CNI functions for a short period of time. Stand-alone (non-operative) BIT is accomplished when the CNI system is not running in an operational mode with the use of operational runtime software. BIT may also include control and interface logic and can be accomplished with combinations of on-line, off-line and start up BIT. Finally, the operator can initiate control and test modes for the system.

This architecture basically used common processing assets that were programmed for a dedicated waveform. The primary issues with this design approach revolved around hardware vs. software flexibility. Although receivers and processors could be reconfigured, software reloading and control was difficult. The level of reconfiguration and flexibility in the system created significant software complexity and added additional tests for qualification, thus increasing performance risks. Reconfiguration also creates significant control software complexity and the amount of BIT and reconfiguration software required to run constantly within the system tended to load down processors. Additionally, the use of VHSIC and ASICs created a cost and schedule issue. When design changes were required for these devices they were very costly and time consuming.

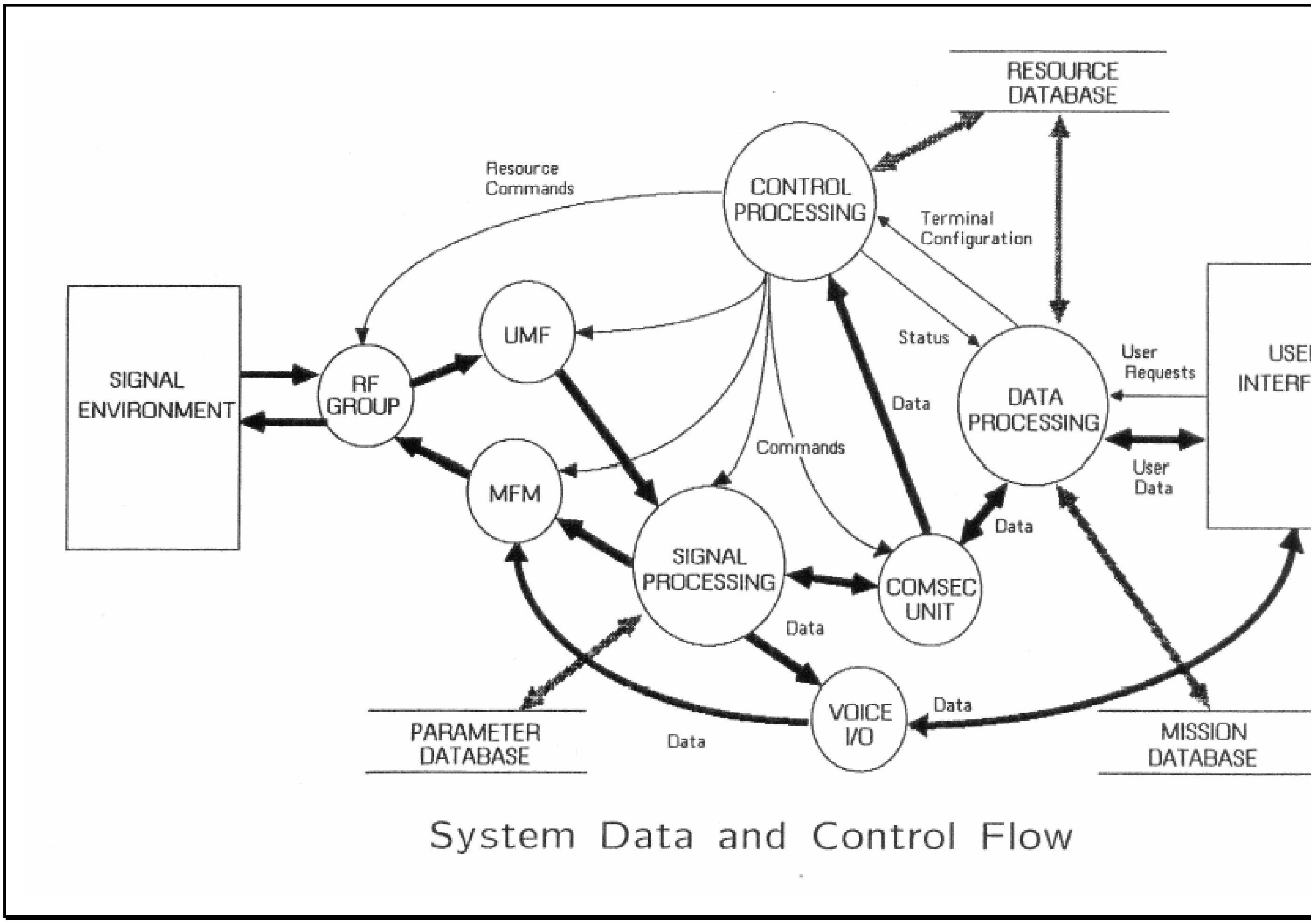

Figure 2-14. Software Resources and Flow

2.2.4. F-22 and RAH-66 Communications Navigation Identification

Lockheed Martin of Fort Worth, Texas, was the prime contractor overseeing the development and integration of the CNI system for application on F-22 advanced tactical fighter. This was an Engineering and Manufacturing Development (EMD) program to design, develop and qualify a design for production of the F-22 aircraft. Boeing Helicopters in Philadelphia, Pennsylvania, was the prime contractor for the development of the RAH-66 Comanche helicopter. Similarly, this program was also an EMD effort; however, it was tailored to the needs of an Army helicopter development effort. Although these two programs started at different times, they began with a single approach to the architecture.

The F-22 Architecture was based on the ICNIA technology and adapted to F-22 requirements. This approach was verified by demonstration in the YF-22 Demonstration/Validation program. The architecture was then upgraded, adapted and tailored to the specific requirements of the F-22 EMD program. The size and “character” of the resulting architecture was driven by F-22 functionality, platform specifics, and simultaneity requirements. The architecture was initially partitioned into processing efficient areas including common core data processing elements in the Common Integrated Processor (CIP), CNI front end processing, and external processing areas remote to the main avionics bay. Each of these processing areas had a specific set of identified interface types including RF, digital, analog, discrete and bus as illustrated in Figure 2-15.

The processing architecture was partitioned into Line Replace Modules (LRM) contained within the avionics bay and Line Replaceable Units (LRU) located remotely. These definitions had to consider total weapon system weight and cost impacts. Numbers and types of these assemblies included only those necessary to meet the F-22 function type, functional simultaneity and reconfigurability requirements. Exact tailoring of the architecture led to the removal of some initially conceived module types, defining new module types, repartitioning of architectural requirements to other existing module types and between external LRUs.

One of the key features of the F-22 CNI architecture is the fault tolerant, reconfigurable capability contained within. The design provides architecture, hardware and software to detect a loss of or degraded functionality of the identified mission critical functions caused by a failed LRM. The design also supports a resource thread reconfiguration using another LRM(s) of like type to regain functionality. These key functions included UHF Radio (Communications), Instrument Landing System and TACAN (Navigation) and Mark 12 Identification Friend or Foe (Surveillance).

This reconfiguration is based on using assets from lower priority (mission software/pilot based) functions which are usurped to provide the backup LRM(s). Hardware is provisioned to provide these, as well as many other options to reconfigure the mission critical functions. However, this reconfigurability was intentionally limited by the selected implementation by the control software. This limited reconfiguration capability reduces the number of configurations that must be tested to qualify and certify the CNI suite for F-22 applications.

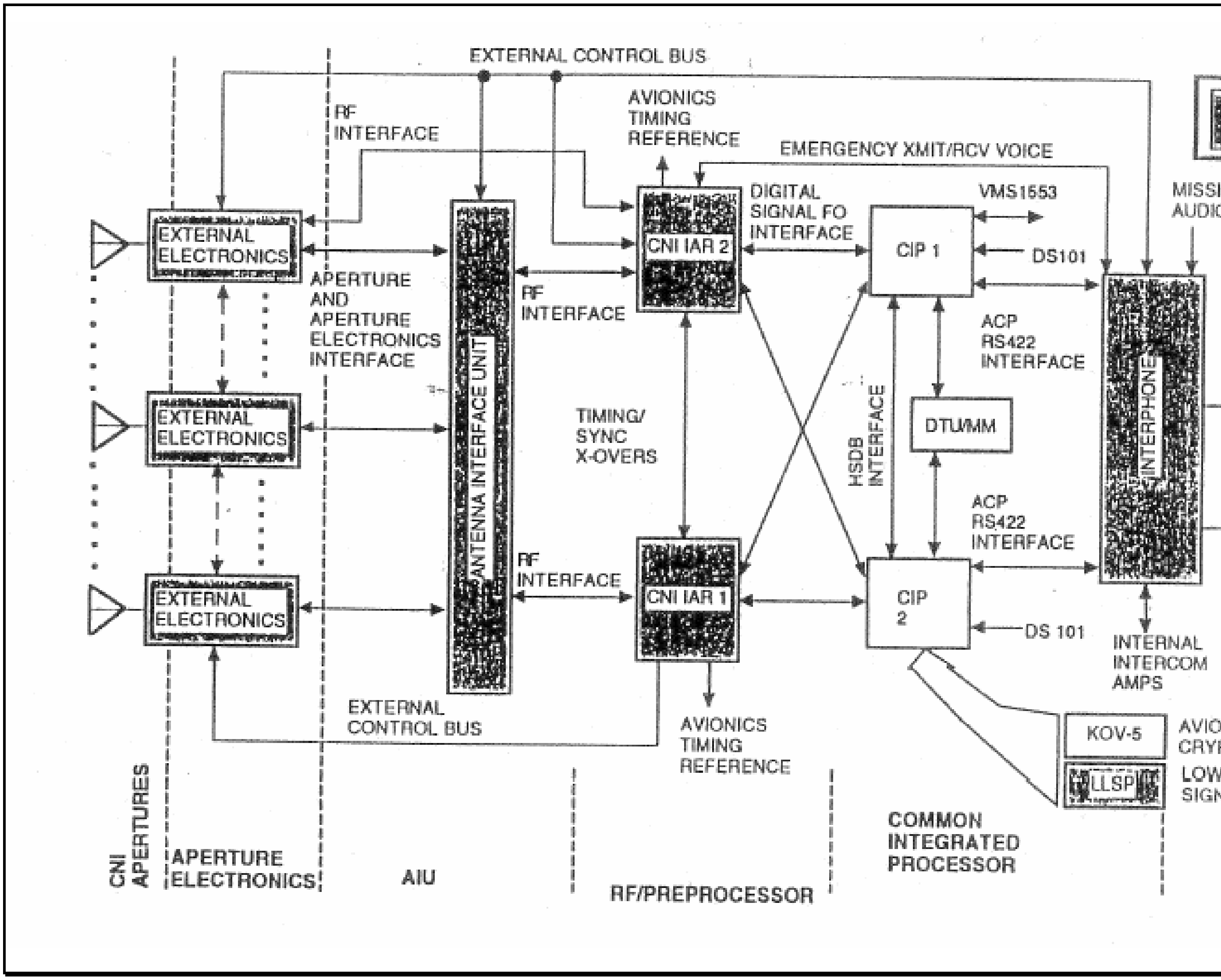

Figure 2-15. F-22 CNI System Topology

The F-22 architecture (bus and control diagram) illustrated in Figure 2-16 took lessons learned from the ICNIA program in determining a more cost effective approach to common hardware and overall system flexibility and reconfigurability. Additionally, these architectures became more software intensive in nature assuming that modifications and upgrades would be significantly easier to implement. VHSIC technology was abandoned in favor of newer ASIC technology that afforded further advantages of size and weight reductions. Common hardware was not only the primary theme in CNI but across the entire avionics system. The multi-band receiver conceived during the ICNIA program was replaced by three separate receiver designs, a common VHF/UHF receiver, a common L Band single channel receiver and a pair of 5-channel L Band receivers made up of components from the single channel receiver. This 5-channel receiver was a more cost effective method of receiving the multiple signals including phase-matched signals required for interferometer functionality. The universal matched filter was also replaced by two separate common digital designs. First, a Pulse Narrowband Preprocessor (PNP) performed signal processing functions for pulse and CW waveforms. Second, a Pulse Environment AoA Preprocessor, like the 5-channel receiver, supports interferometer functions. The Spread Spectrum Preprocessor processes wideband signals like those used for Link 16. As in the ICNIA architecture, the power amplifiers are custom designs specifically implementing waveform specifications. However, these designs contain the exciter/synthesizer that were stand-alone assemblies in the earlier design.

A high-speed fiber optic bus developed by Harris Corporation interconnects the CNI RF front end with its associated common processing elements. Signal and data processing for all waveforms were performed in a program directed Common Integrated Processor (CIP). The CIP signal and data processors were not necessarily optimized for the CNI applications but provided a common design for control and interface of all avionics that were demonstrated in the YF-22 program. [The YF-22 program used ICNIA hardware and software.] Transmission security (TRANSEC) and Communications Security (COMSEC) were provided by NSA sponsored integrated, multifunction security modules. These common processors reside in a different enclosure in the avionics bay and are reconfigurable to be used by CNI, electronic warfare, radar, display and/or mission computers.

Although the bus structure on these designs was improved to minimize performance shortfalls, the structures are proprietary in nature. Open architecture bus structures were rejected because of the complex threaded software control structure that was implemented through major portions of the system.

The majority of the software in both of these architectures was newly developed using the Ada software language and residing on a common executive and a common operating kernel. These common software packages that interfaced the software applications to the processors were proprietary in nature. The complexity of the software and the operating system was justified due to a requirement to operate the system in a multi-level secure environment. This is due to the fact that while multiple functions are operating within this radio simultaneously, they are not all operating at the same security level.

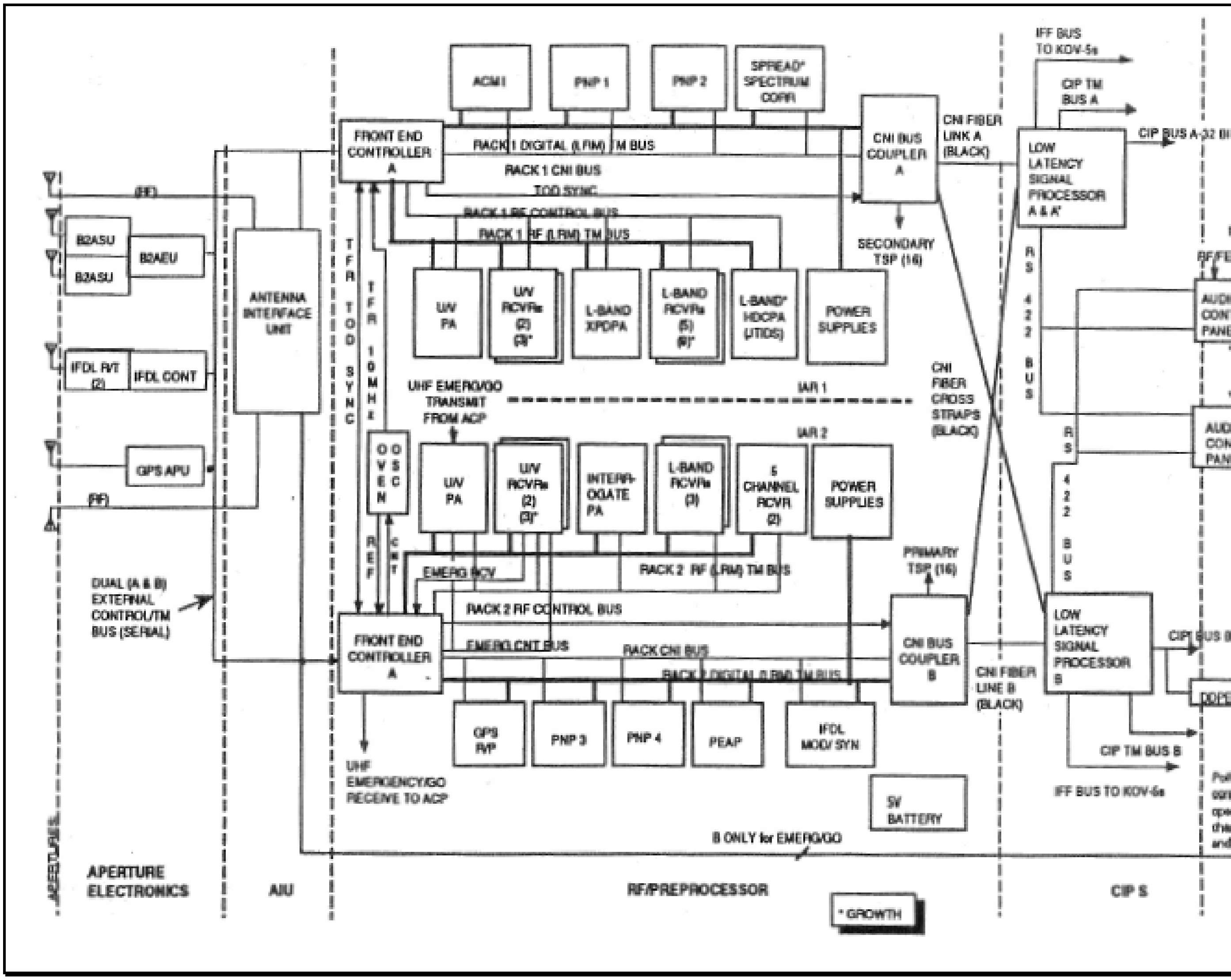

Figure 2-16. F-22 CNI Architecture

To mitigate software development risk, a common tool set was developed by Lockheed Martin and used by all of the major software suppliers supporting the F-22 development. The F-22 program used a single software development plan, conceived by Lockheed Martin and followed by all of the contractors. This included common development methodology, interfaces between contractors to discuss development and tool issues, and the interfacing of quality and configuration control personnel to ensure sharing of both successes and shortfalls.

One of the primary issues discussed earlier is to intentionally limit reconfiguration. This was a cost and complexity trade. An attempt to qualify a significant number of cross connection paths for reconfiguration adds significant risk to a qualification program, especially when security is a primary issue. The integration of this architecture was also a significant challenge. Because of the threaded approach to control, functions sharing processors, and functions distributed across multiple processors, small software bugs and performance shortfalls had a significant impact on the ability to test and integrate the system. Because software dominated the architecture, performance of software through processors became a pacing issue in qualification of both the software and the system.

Additionally, the threaded control structure created bus contention issues, causing the system software to freeze. This created a need to constantly reboot the system until these contentions were investigated and fixed.

A simple lesson learned is to balance the hardware portions of the system with the software. More simply stated “build the portions of the system in hardware or firmware where functions and algorithms are unlikely to change”. In theory, this will work well if you do not have to redesign key elements of the hardware often. As in the case of the ICNIA system, both F-22 and RAH-66 experienced significant redesign of ASICs causing cost over runs and schedule delays. This occurred in some measure because most of the redesign issues did not surface until the integration and test phase of the program.

The RAH-66 received a contract modification in 2003 to design software compliant with the JTRS and SCA architectures and requirements. This became a significant departure from the basic architectures adhered to from the F-22 CNI. This contract requirement presents a significant challenge because the bus structures and hardware do not comply with the open architecture standards and the software must comply. This means abandoning the current operating system for CORBA or a CORBA modified design and changing the software architecture to a more independent object oriented design. This approach is currently under development, and the software design will feed forward as reuse software to the Joint Strike Fighter CNI program.

2.2.5. F-35 Joint Strike Fighter Communications Navigation Identification (CNI)

Lockheed Martin, Fort Worth, Texas, is the prime contractor overseeing the development of the integration CNI system for application on F-35 Joint Strike Fighter. This program is currently in the Engineering and Manufacturing Development (EMD) phase. The program will design, develop and qualify a design for production of the three variants of the F-35 aircraft. This program will use an architecture that is JTRS and SCA compliant. This architecture will be a combination of open architecture hardware and specialty designs to meet the challenges of multiple complex waveforms. Commercial bus structures will be used for internal CNI interfaces, while a slightly modified commercial fiber optic high-speed bus will be used to interconnect various assets within the avionics architecture. Unlike the F-22 architecture, all key common processing elements are enclosed with the CNI front-end assets to enhance the throughput and performance of the system. One of the proposed architectures is illustrated in Figure 2-17. Although this is not the final architecture accepted by the customer, it represents the basic approach to addressing many of the issues that surfaced during the development of earlier products.

Although common hardware is still a principal theme in the architecture, waveforms will be demodulated and processed in self-contained threaded designs. Hardware chains that are assigned and programmed include receiver/exciters, preprocessors, signal processors and embedded cryptography. These chains are then interfaced to General-Purpose Processors (GPP) for data and display processing purposes. Control will be embedded in these chains with only higher-level management commands executed from the data and control processors. Additionally, ASICs have been replaced with Field Programmable Gate Arrays (FPGAs) and flexibility and cost reduction to the overall hardware suite. Using FPGA technology will allow algorithms to be tested on hardware early in the development process. Adjustments can be made without altering hardware, thereby reducing the risk of major redesign efforts during test and qualification.

A clear outcome of the initial JSF CNI studies and analysis is the application of CORBA to the CNI design. Since the system has a multi-level security requirement, it is not possible to have unlimited paths of interconnection for the various software elements. The CNI system has adopted a modified CORBA type design that is proprietary to Marconi/Selenia that limits cross connections through the use of a privileged routing table. This format limits data of different classification levels from being passed to elements at a lower classification level by specifically addressing classified elements in the system. Without this modification, security certification would never be granted to a system that can operate 12 functions simultaneously in a multi-level secure environment.

The software structure is envisioned to be independent object oriented designs that are independent of hardware. This enables processor upgrades to take place with minimum impact to previously qualified software. Software development for this program uses a series of processes from simulation of the interfaces and internal performance to prototype software modules integrated as early as possible on target processors to wring out performance and interface issues. A series of proprietary design tools are being combined with commercial tools like DOORS (requirements traceability tool), Rational Rose and Rhapsody to allow use cases to be developed for software. The use cases are then modeled and performance analyzed. Tools like Rhapsody can even be used to auto generate code after the engineers implement the key design algorithms.

The key to the Joint Strike Fighter architecture is the application of the system control requirements. CNI control requirements are characterized by the need for non-blocking real time control of assets like receivers, transmitters, power amplifiers and antenna interface units and Time of Day (TOD) distribution while meeting the stringent turnaround requirements of

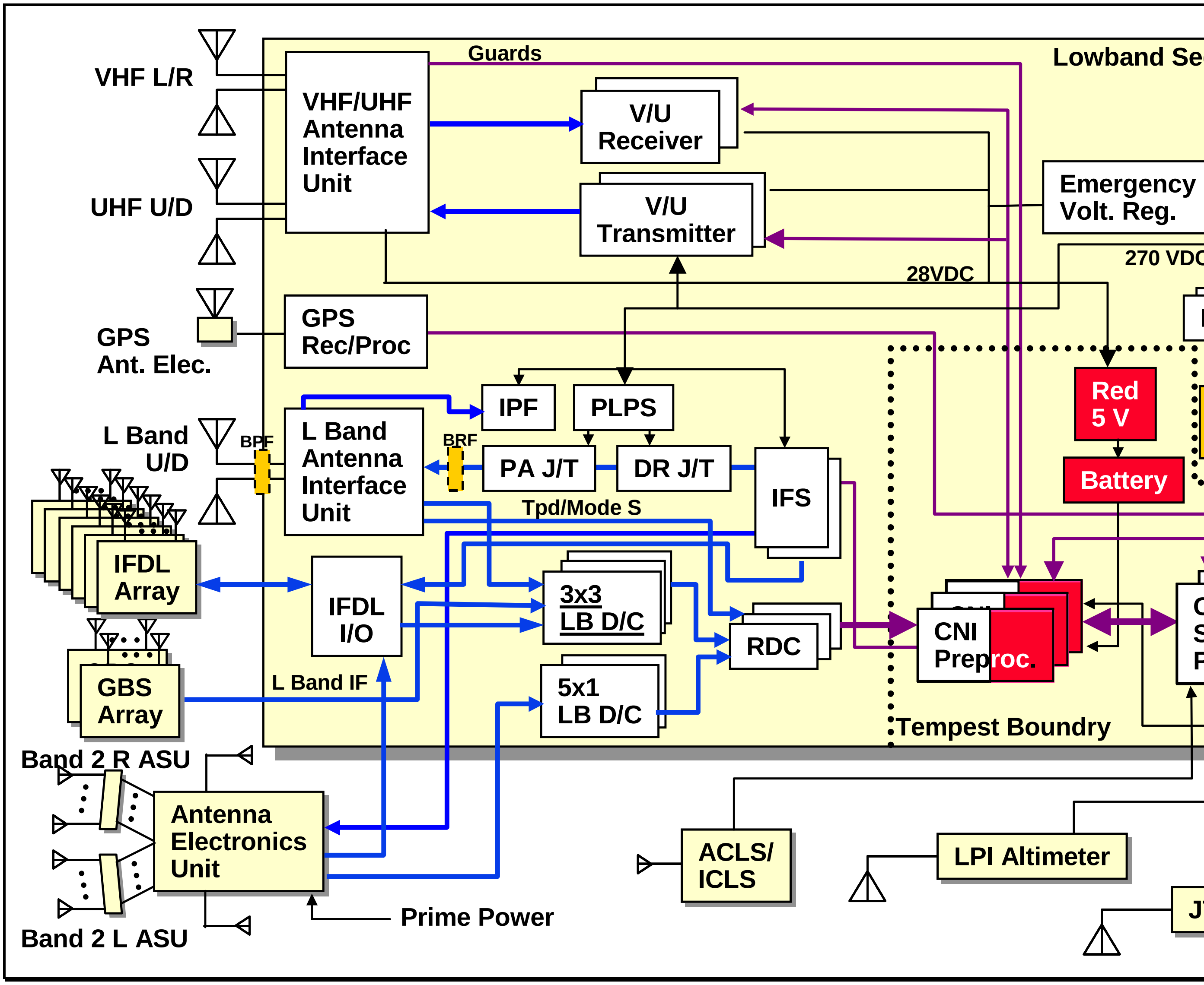

Figure 2-17. Conceptual JSF Architecture (Proposed)

functions like JTIDS round trip timing and/or IFF transponder reply. The control architecture must accommodate simultaneous CNI functions with the control of assets numbering more than 25 channels.

Various control network configurations were considered in light of emerging technologies, and a dual counter rotating ring gigabit serial link architecture with cross ring relay capability was chosen as illustrated in Figure 2-18. The requirements on the interface node to this network have been derived and a preliminary architecture for the interface node was developed. Critical timing issues like JTIDS and IFF transponder that are based on message driven and hardwired discrete events have been analyzed for compliance with this architecture. Timing budgets have been developed.

Based on the integration and test on the F-22 program, lessons were learned that left the JSF program with a goal that any functional operation within the system is deterministic in nature. Malfunctions or failures in one waveform should not affect other parts of the system. This is provided with time slotted access to processing assets such as FPGAs, DSP and the GPP.

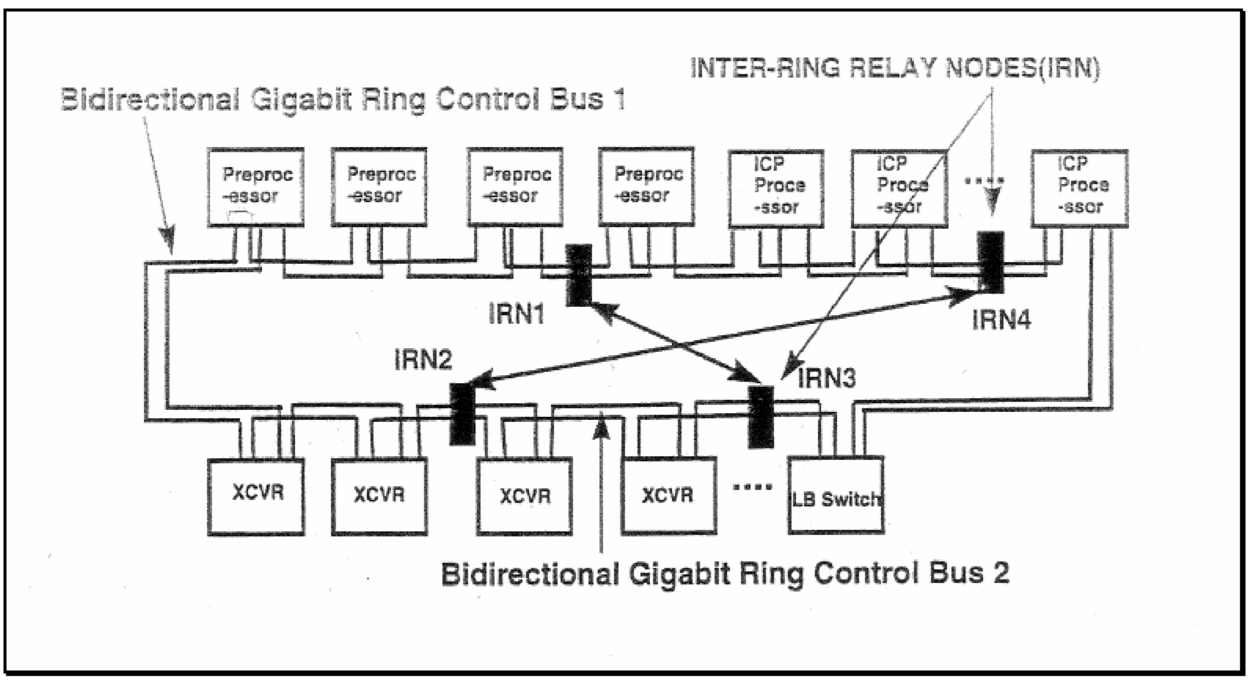

Figure 2-18. Bi-directional Gigabit Ring Control Bus

The highlights of key requirements used to generate the control architecture requirements are:

- TRANSEC transfer with low latency

- Enable fine grain resource sharing in real time (TACAN/Link 16)
- Wide bandwidth, non-blocking fault tolerant network
- Universal communications among resources: addressed, broadcast and multicast
- Bandwidth to support event-by-event control of resources
- Bandwidth to support low latency requirements for all simultaneous CNI functions with each software module executing in it's assigned timeslot within the 7.8125 epoch (to force deterministic behavior) (Link 16)
- Broadcast message transmission to all assets with minimal skew
- Enable the use of discretes between processors and other assets requiring extremely low latency
- Transparent to the addition of resources

2.2.6. MITRE Corporation Vision of Software Defined Radio

MITRE has been conducting studies and architectural analysis to the feasibility of Software Defined Radios (SDR) and challenges. The MITRE view of SDR is a confluence of technologies and architecture that not only allows but also encourages the maximum use of digital processing; i.e., General Processing Units (GPU), Digital Signal Processors (DSP), Field Programmable Gate Arrays (FPGA) and Application Specific Integrated Circuits (ASIC). The SDR technique is the heart of the radio that uses standard interfaces making software independent of the hardware implementation. The RF side of the design can be reconfigured in-situ to take advantage of regional spectrum availability. This flexibility will require advanced configuration control to ensure ready porting to new hardware and easy end user changing of the radio's fundamental nature. In order to evaluate the technology to be implemented for an SDR design, the architecture as illustrated in Figure 2-19 is mapped into domains.

The Radio Domains are:

- Digital
- IF
- RF

The Technology Domains are:

- Digital Processing
- Middleware

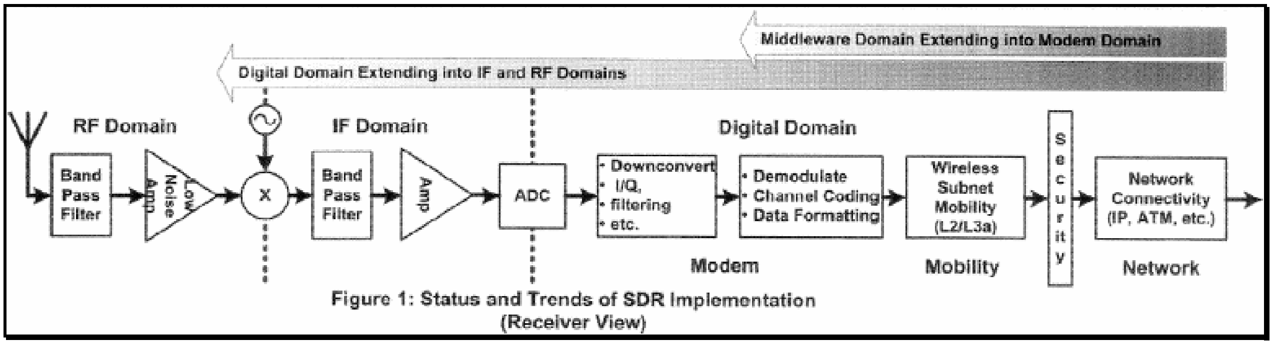

Figure 2-19. SDR Implementation (Receiver View)

There are two main operational flexibility goals for a software-defined radio. First, the "field configuration" goal allows the user to change the fundamental functionality of the radio to meet changing operational and/or environmental needs. Second, portability is defined as the ability to apply any set of radio modules up to and including an entire radio to any radio transceiver hardware implementation. To achieve these goals, the software to processor interfaces need to be defined without ambiguity. This implies defining the interfaces and keeping them stable. The functionality of services provided for applications needs to be defined, again without ambiguity. The key element following the interface and function definitions is the ability of the designers and programmers who must implement with the use of only pre-defined interfaces and core functions. If they implement other functions or interfaces, the flexibility, reconfigurability and upgradeability may be lost. These implementations will require a well-defined and controlled operating system such as real-time POSIX. The implementation of software requires standardized platforms conforming to the Software Communications Architecture (SCA).

In the past hardware centric radios were heavily optimized for performance. In a similar manner, performance of each module of the SDR must be carefully analyzed, instrumented and tested. Software implementation will require an object-oriented approach. However, performance concerns include extra processing for intra-ORB and inter-ORB communications that causes unacceptable latency, jitter and throughput restrictions. In many cases the effect is not well documented. A recent investigation, which included a detailed instrumentation of the design approach, indicates that with the proper use of real time extensions to CORBA and a proper inter-ORB architecture the added latency can be limited to less than 5%. CORBA alternatives to date have less data available from controlled test setups to allow any conclusions to be drawn as to its effect or advantages for the SDR architecture.

The modem end of the design has tight performance requirements including I/O processing, modulation/demodulation, timing recovery and forward error processing.

Typically, one or more DSPs, FPGAs and/or ASICs are used to meet these high performance requirements. Future designs may include the creation of a "virtual modem" in the GPU. This will allow the SDR architecture to be maintained. Another alternative may be a hardware abstraction that uses middleware to route commands through the operating system kernel to/from the DSP or other processing devices. Once again, interfaces and functions cannot be changed to meet the performance requirements or the spirit and advantages of a SDR will be lost.

Both the RF and digital portions of the SDR have a number of challenges in the hardware design. As more processing elements are required and the speed is increased, more power is used and the heat generated must be dissipated. For smaller designs like backpacks, handhelds or embedded devices, limited heat dissipation and battery size, weight and capability will provide additional challenges. Some RF modulations and waveforms require high peak power further challenging power amplifier and heat dissipation designs.

Most current or envisioned commercial and government applications involve the movement of IP datagrams across a mixed network of wireless and land connections. The mobile network must have a capability to form sub-networks, underlying the larger overall network. This will include features like node entry and exit to the network, topology/architecture optimization, mobility and adjustment to mobility and adverse environmental factors and finally, network and spectrum management. The mobile sub-network is usually separated from a landline network by a security barrier. The level of encryption is based on the specific needs of the government or commercial application.

The SDR must possess the capability of an RF interface compatible with any existing RF devices until they are ordered out of the field. This suggests that there is a one-for-one compatibility and replacement of function, not necessarily a one-for-one hardware replacement in size and weight. Legacy radio waveform software will have to be ported into the initial SDR design. This must be done while minimally modularizing the existing software code. Additionally, the legacy software must be wrapped with code that presents a compliant interface to the SDR middleware and operating system.

SDR will bring additional challenges to waveform implementation. Since most of the future applications will be more data intensive, a significant increase in bandwidth is highly desirable. This can be a significant issue since the available spectrum, which is partitioned into smaller frequency blocks, is heavily used. Four approaches to address these challenges are considered:

- Higher order modulations
- The additional of spatial diversity, known as directional antennas
- Use smaller portions or chunks in the unused or underused spectrum, creating the equivalent of a single broadband channel (OFDM)

- With maturity of product, a combination of these approaches maybe the most practical design for implementation of an SDR

2.2.7. General Dynamics View of Extending CORBA into Software Defined Radios

The US Navy funded an effort to develop a Digital Modular Radio (DMR) with common processing elements and an open architecture approach to building both software and hardware. Application of CORBA within an SDR design facilitates significant design flexibility. It was determined through this effort that CORBA facilitates redeployment of objects to a variety of processing resources including simulation environments. Routing of communications from an object to other known objects on any other processing resource can also be accomplished. During the course of the DMR program, quick creation of applications via modification of high-level application topology scripts was used to specify new connectivity for objects. This capability resulted in the creation of a radio simulcast capability within a matter of hours for an Open System Architecture (OSA).

CORBA also provides real time mechanisms for the deterministic operation necessary within an SDR. Data path reconfigurability for loop back and retransmission is also a feature exploited in the CORBA based design. A typical SDR environment is illustrated in Figure 2-20. Each of the processing assets is tailored to meet the requirements of radio applications.

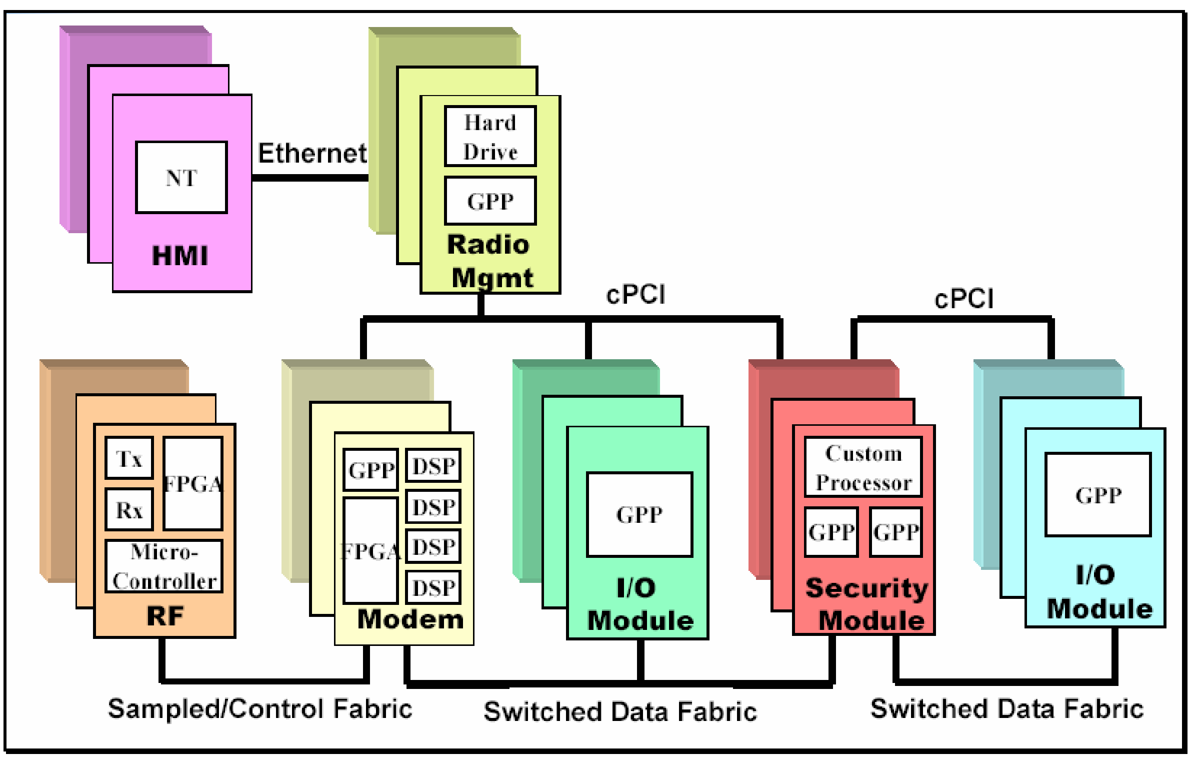

Figure 2-20. Typical SDR Environment

Using this open architecture approach, virtual hardware abstraction facilitates flexible assignment of waveform software components to processing assets as illustrated in Figure 2-21.

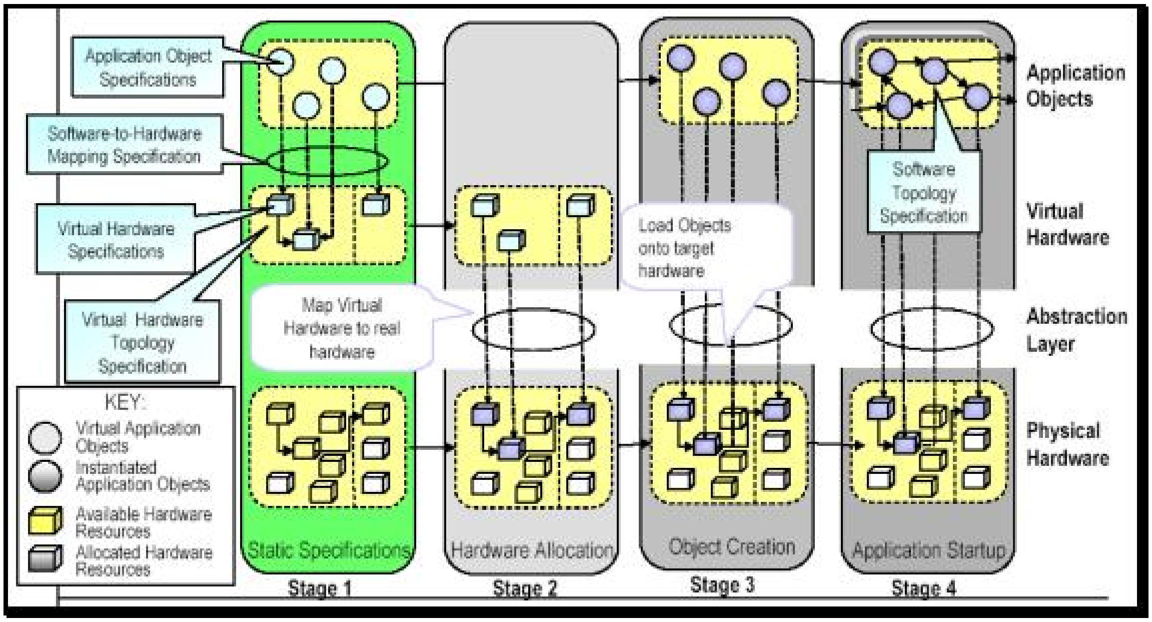

Figure 2-21. Radio Application Instantiation Process

Of course one of the substantial issues with CORBA and a fully open architecture is data security and routing of data from one processing element to any other processing element. This design issue is solved through addressing schemes and aliasing to provide a means for dictating client/server transport mechanisms and segregating control/data as detailed in Figure 2-22.

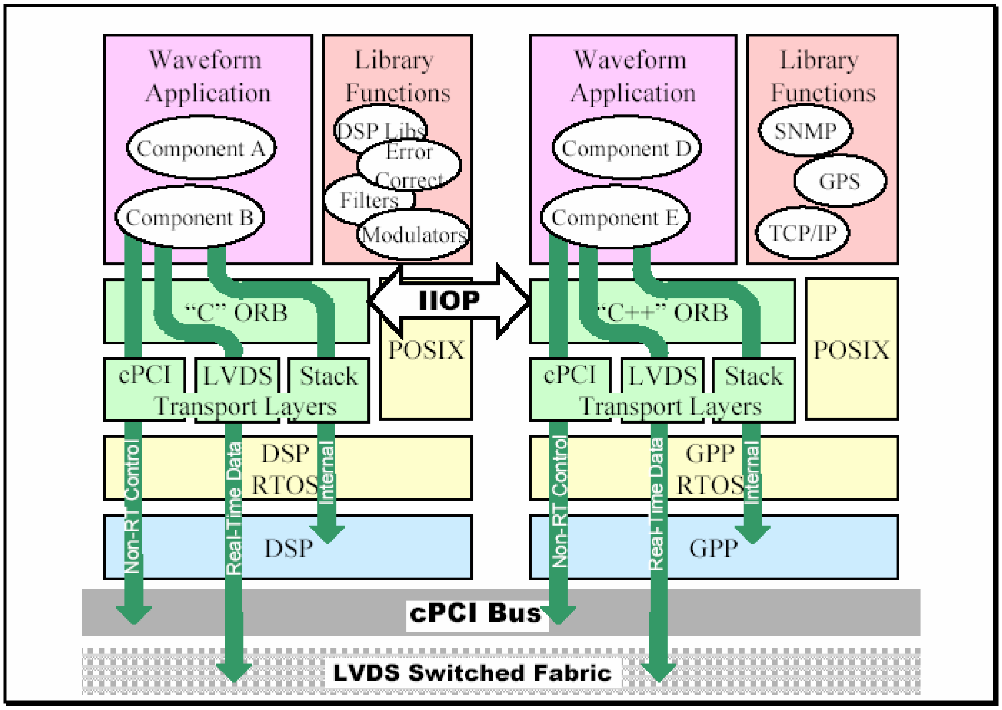

Figure 2-22. Pluggable Transport Alternatives to TCP/IP

CORBA real-time policy extensions allow deterministic operations to be possible through time-out and priority mechanisms not available on standard CORBA. These features include priority mapping, mutex interface for locking access to CORBA implementations, thread pools or processing lanes to prevent encroachment by other signal threads, private connection policy and invocation timeout to provide a uniform method of specifying timeouts relative to connection failures. All of the features are needed to implement the kind of security features required for a military or sensitive commercial application.

The MDR program provided analytical evidence that CORBA implementation would not negatively impact a software defined radio approach. One initial issue with CORBA was memory utilization creating a memory shortfall within critical DSP assets and runtime overhead heavily taxed processing time budgets. Both of these issues were addressed utilizing a TI C5510 DSP, much less powerful than the assets available in June 2004.

Even using the older devices, CORBA used less than 20% of available core memory and had latencies of 8.3 microseconds in a 40 MIP DSP processor. Many engineers believed CORBA was not appropriate for non-Object oriented languages like C. MDR proved C could be implemented and provide the user with a level of control over realizations of inherited operations. The largest concern for military applications is that the flexibility offered by CORBA is unnecessary for the embedded environment of an SDR. MDR showed that CORBA provided fault tolerant mechanisms, which facilitate fail-over to secondary objects. The design showed how CORBA can provide a means of dynamically switching an SDR data path to bridge communications. Finally, the key to the effective use of CORBA in an SDR environment is the blending of minimum CORBA with optimized transport layer, pre-connects and real-time processing mechanisms.

2.2.8. Rockwell Collins View of Impacts of OS and CORBA on SDR

By the time SDRs were actually a viable approach, the government was tired of paying for the same functionality over and over to achieve different services. This was the premise on which the JTRS and other SDR efforts were launched. The selection of the SCA architecture for these applications brings positive impacts to the design as outlined:

- Clean re-development of legacy software waveforms
- Standard application interfaces (API)
- CORBA based inter-object communications
- POSIX Compliant Operating System

These are real and tangible benefits that will become financially measurable as time passes. SCA compliance becomes an investment into America's defense infrastructure. This investment has costs, risks, growing pains and rewards as stated below:

- Applications designed to be hosted under a "Common Operating Environment"

- SCA compliance should result in many of the same PC benefits industry gained in the 1970s

- Re-use from JTRS JPO Technology Library will allow re-hosting for porting costs, instead of a complete new development

A question to be answered in an avionics environment is: "Does SCA implement in applications that are power limited?" This implies that gaining the desired benefits from the SCA vision requires investment and a technological maturation process. JTRS cluster 1 is performing groundbreaking development in SCA compliant architectures, applications, operating systems and middleware. However when applied to the dense power and cooling starved avionics environment, challenges are still prevalent. Power and cooling have a negative affect on avionics design and for a software defined radio these challenges are not minimized. First, functions that were implemented in mature, power efficient analog technologies have been converted to less power efficient digital technologies. Second, the overhead to make software portable is inefficient for real real-time radio waveforms when compared to hand crafted software of the past.

It is important to review past and modern architecture of radios to determine impacts of using an SDR approach. Figures 2-23 and 2-24 illustrate traditional radios and modern SDR radios.

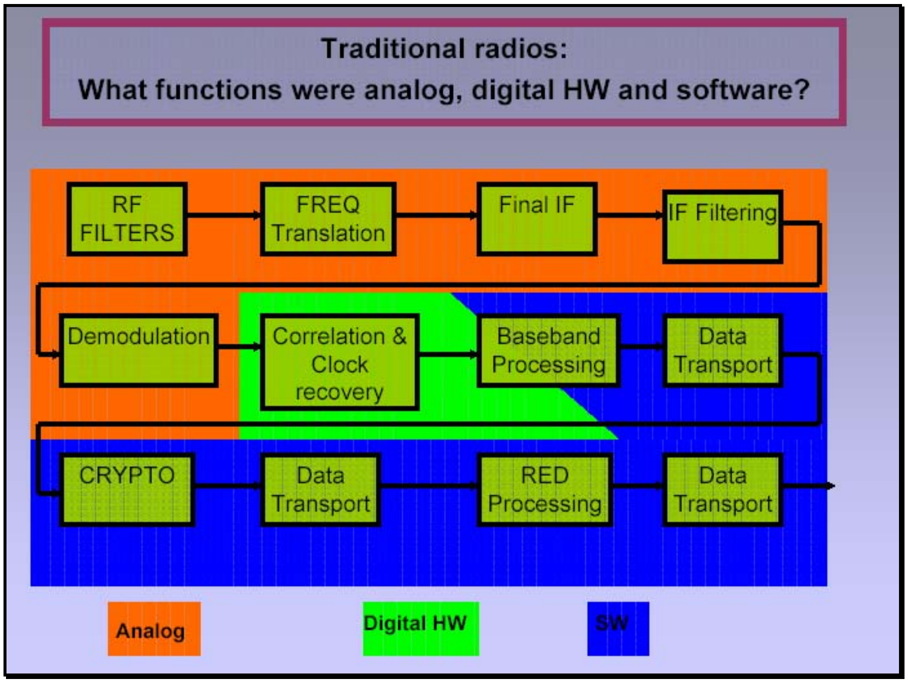

Figure 2-23. Traditional Radio Architecture

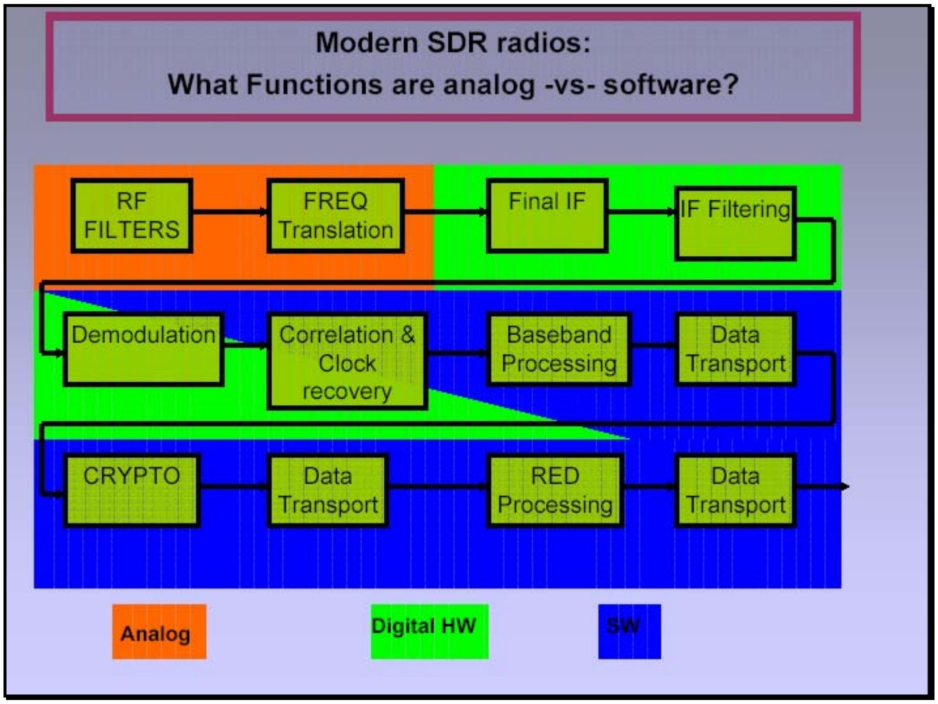

Figure 2-24. SDR Radio Architecture

A quick review of the architecture shows a significant migration to digital technology and digital functions. Hardware functions have been implemented in VHDL applications. Inter-function communications have become standardized using CORBA, and data is repeatedly copied and moved because of operating system and middleware constructions. These architectural changes have created additional requirements (digital reuse, portability and standardization processing) which increase the need for power and cooling. Power is an issue due to the limited battery life of handheld and small radios and because of the lack of power and cooling in most modern aircraft. A closer inspection of the software architecture illustrates the need for extra throughput as illustrated in Figure 2-25.

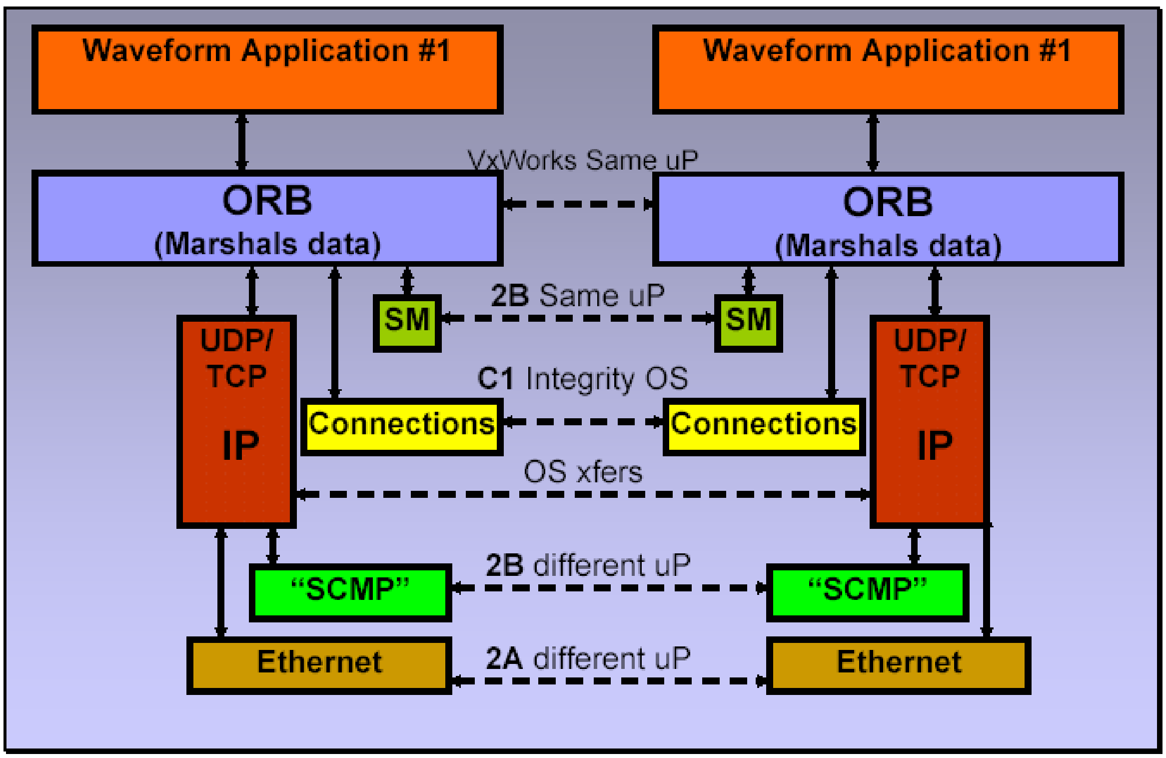

Figure 2-25. Software Architecture Need for Throughput

The rate of hardware improvement, although moving rapidly and deployed every 15 - 18 months, cannot match the potential that exists in improving the inefficient middleware and operating system. Marshalling data and efficiently moving it from one processor to another is simply not a complex problem when compared to the Link 16 waveform (approximately 80 Ksloc). Yet, the ORB (100 Ksloc) requires more source lines of code. A more efficient architecture for applications that are power or size restricted is illustrated in Figure 2-26.

Analysis indicates that changing core framework and operating systems may have limited benefit to a software defined radio requiring very challenging round trip timing. If a core framework required zero MIPS, many runtime problems would still exist. The most effective benefits maybe obtained from changing the view of how things are done in the software world. CORBA data marshalling is a straightforward operation of data organization. It provides the opportunity for improvement in algorithms and sorting techniques. The software defined radio community of developers must support OMG in completing the definition of the "Pluggable Protocol" so a high-speed, inter-process interface can be implemented that is portable across platforms. Finally, ORBs and OS should be developed using a new paradigm where data is not moved up and down a protocol stack, but pointers are passed.

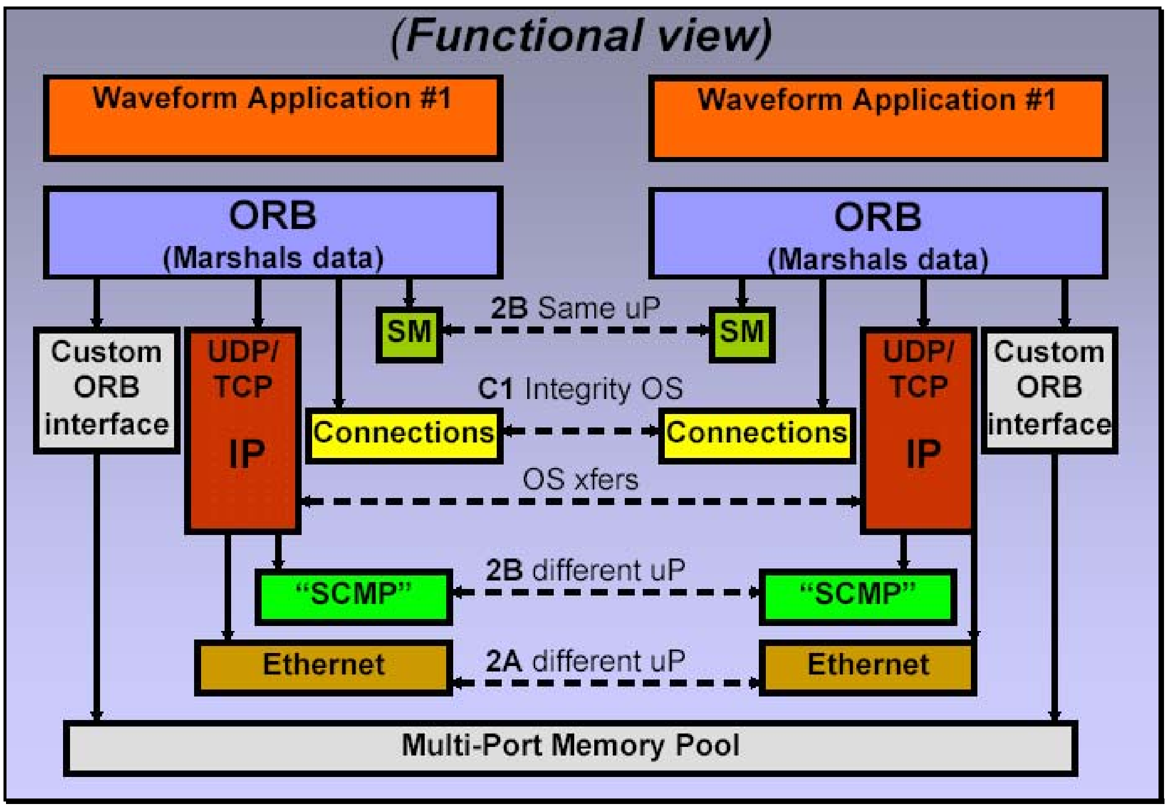

Figure 2-26. Power Restricted Applications

2.2.9. US Government (Customer) View of JTRS and Software Defined Radio

One of the major questions that the Department of Defense had to answer was the need for a JTRS Radio. If SDRs are available, why was there a need to develop a JTRS?

The proliferation of unique SDRs with unique architectures and implementations have continued many of the original problems of legacy radios. This leads to interoperability issues, support problems and system/network modifications. From the DoD standpoint, battlespace flexibility is also a major design drawback of these SDR approaches. The

DoD decided they needed a common hardware open architecture approach with SCA architecture as the foundation of the design.

The DoD focused on an architecture that combined SCA with open standard interface rules and protocols as illustrated in Figure 2-27. The government would retain ownership of waveforms and cryptographic algorithms, but the open architecture approach would allow multiple suppliers and participants for a more cost effective approach. The view of the past is communications needs were separated into single mission boxes. These boxes addressed only communications or Signals Intelligence (SIGINT) or Electronic Warfare (EW) or interoperability.

The future vision for JTRS is a programmable system that can perform a large list of functions (30 and growing) and serve all needs on any platform for any mission or multiple missions. Plus, the key element is that this must happen anytime. Because of this multi-mission, software reconfigurable centric view of JTRS, the government has challenged developers to provide products that are not only reconfigurable, but also dynamic and responsive to a complex mission mix.

The heart of the system is the SCA concept. The government views this architecture as the consensus of the best commercial practices and technology. They developed a plan to take SCA from a commercial product to a standard for use in JTRS applications. This approach uses the analysis and design skills of many of the JTRS participating contractors to formulate an SCA definition that will evolve into the final standard. This standard will not only be applicable to the US marketplace but also to many international development projects. This is a key point to ensure future interoperability of radios. This concept is illustrated in Figure 2-28.

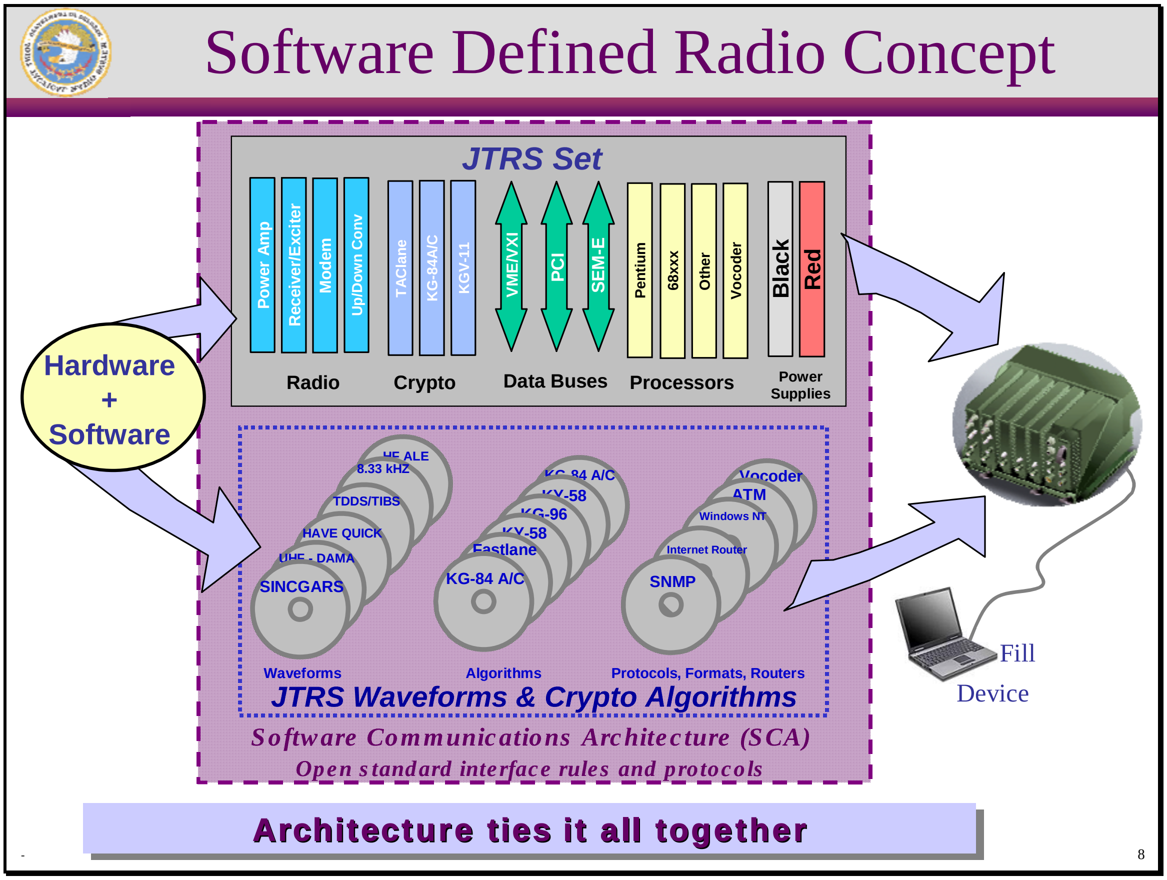

Figure 2-27. JTRS Concept

The key to successful implementation of the SCA standard is the acceptance of the interfaces by the developing engineers. The proliferation of special purpose designs created a significant interoperability problem, increased the support and logistics costs and increased both the cost and risk of qualification. Developing future JTRS designs with the standard will not only reduce cost and risk but will also allow upgrade paths to be defined and used, extending the life of the product in the field.

Use of the SCA standard will also tie the government designs closer to the commercial world. This should reduce the impact of many of the out of production parts in current radio systems. The open architecture approach will also enable multiple companies to participate in initial and upgraded designs. This may ensure future support to products even if the original design organization no longer exists.

In addition to setting the SCA as the standard for JTRS type radios, the government has also created a JTRS product development process roadmap. This roadmap addresses the parallel development of both hardware and software. This process, illustrated in Figure 2-29, outlines a key element of the process, the development of waveform and INFOSEC requirements that feed the parallel development tracks. A principal output of this process is a waveform and algorithm library used for future improvements, new designs and support of the fielded products.

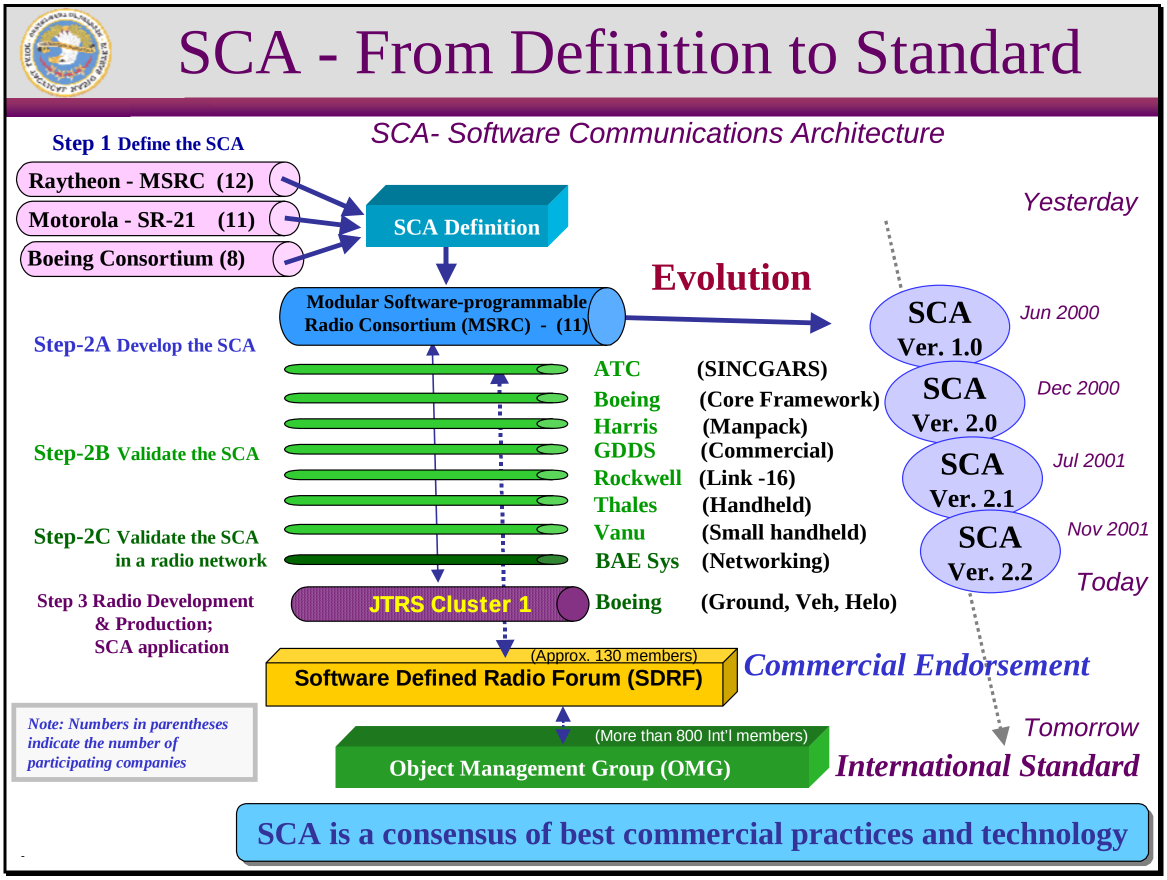

Figure 2-28. SCA Development Concept

Hardware development uses the basic waveform requirements data and added platform specific guidelines to specifically target the design to an application: ground, mobile, airborne or maritime. Hardware verification includes architecture and interoperability with software, yielding a SCA compliant hardware product.

On the software side of the design, the waveform requirements feed into the software guidelines that in turn are used to target the specific software development tools used. These may vary based on final target processors or application. As the waveforms and cryptographic algorithms are developed, they are ported to a test target processor to determine if performance enhancements are required. Software verification is accomplished using target and deployed hardware and, as in the hardware development path, will yield SCA compliant product.

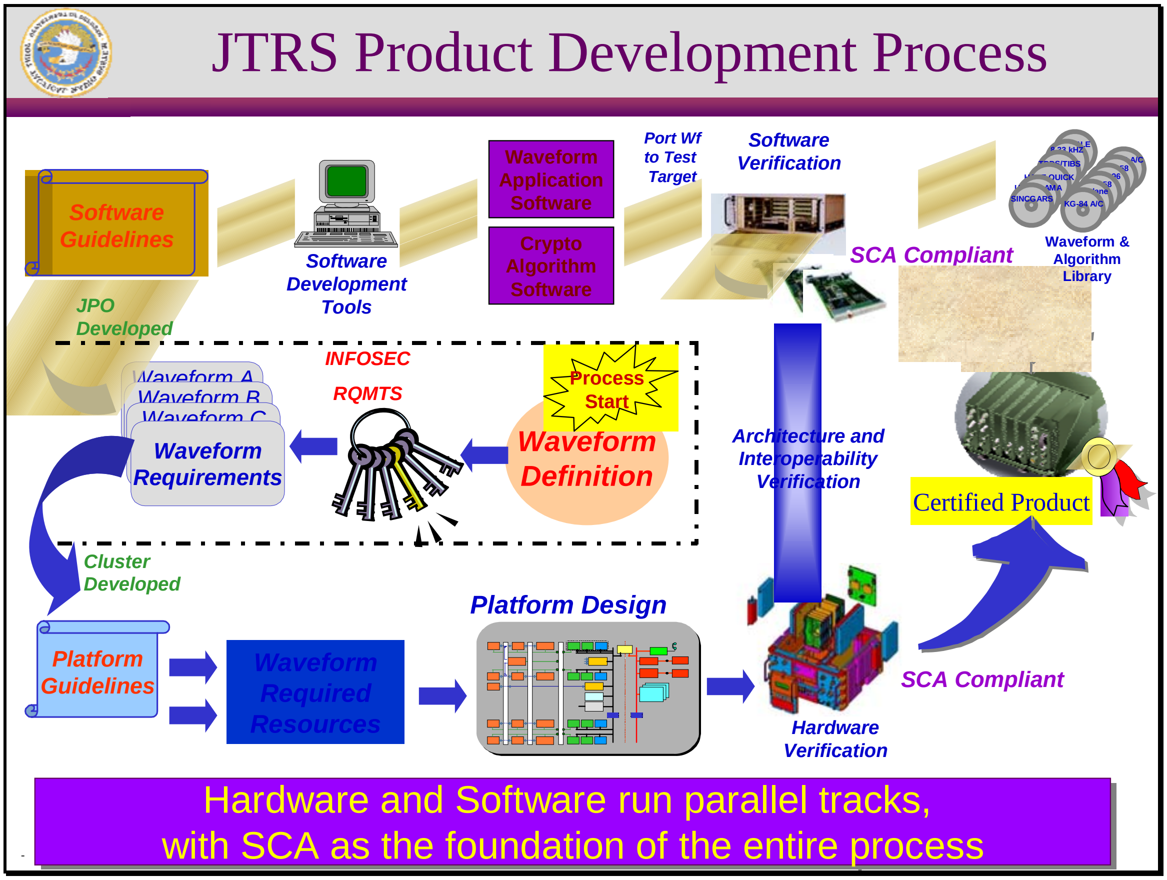

Figure 2-29. JTRS Product Development Process

2.2.10. JTRS Overview and Influences on MMDA Architecture

The US Army has led the way to create an open architecture, interoperable set of radios that are upgradeable in the future through JTRS. The JTRS program, which now encompasses all three services, is based on an open hardware architecture providing for a modular radio design. The development effort is being accomplished in phases known as clusters with the US Army leading the way with Cluster 1. The US Government will own the waveforms and the module level interfaces, allowing new signals in space to be added and taking advantage of the existing networking and INFOSEC capabilities.

The software within the design will be SCA compliant providing additional modularity and upgradeability to the radios. The expanded capability is not limited to the digital and software portions of the design. Power amplifiers and transceiver modules will also take advantage of the latest technology to improve performance. Cost will be reduced through competition. Third parties can develop new hardware and software elements because of the open architecture approach. This will provide competition that drives costs down and innovation up.

There are 5 basic categories for development of JTRS radios all coincident with the final deployed application. These efforts have been funded separately by the US government and are being designed, developed and fabricated by various manufacturers around the country.

- Cluster 1 includes Army air and ground vehicles
- Cluster 2 is the design of hand held radios in the 2 - 512 MHz band only
- Cluster 3 supports maritime and fixed installation sites
- Cluster 4 is airborne
- Cluster 5 encompasses man-packs, handheld radios and Small Form Factor (SFF) radios. These SFF designs support vehicles, Unmanned Air Vehicles (UAV) and Unmanned Ground Vehicles (UGV), netfires, missiles and ground sensors.
- Cluster 6 is not currently planned. If developed, it will include space based radios, SATCOM and waveforms above 2.0 GHz.

Based on the applications, Clusters 1 and 4 seem to be the most applicable to the MMDA approach and technology. The list of functional waveforms to be implemented by JTRS is provided in Table 2-3, which was extracted, from the JTRS Operational Requirements Document (ORD). A JTRS "waveform" is implemented as a re-useable, portable, executable software application that is independent of the JTRS operating system, middleware and hardware. Here a waveform is more than just the "signals in space" physical layer in the OSI stack. It also includes the upper layers (i.e., Internet protocols)

JTRS Cluster 1 is defined as a set of designs supporting both ground and air vehicles for the US Army. Cluster 1 (Air Force TACP, Army rotary wing and Army/USMC vehicular platforms) was awarded to Boeing as the prime contractor. Cluster 1 will provide a functionality suite of legacy military radios and develop the new Wideband Network Waveform (WNW). ViaSat is supporting the Cluster 1 effort by providing the embedded programmable cryptographic capability for the High Assurance Internet Protocol Interoperability System (HAIPIS). The subsystem being developed is the High Assurance Internet Protocol Encryptor (HAIPE) for WNW. Ground radios include three programmable channels, while the airborne version includes four programmable channels as depicted in Figure 2-30. These designs will interface with legacy control panels and antennas and includes a two-level maintenance concept allowing failed hardware to be replaced at the vehicle maintenance level.

Table 2-3. JTRS Waveforms (By Priority: KPP / Threshold / Objective)

ID	KPP (K)	ID	THRESHOLD (T)	ID	OBJECTIVE (O)
W1	*SINCGARS ESIP	W7	UHF SATCOM Military Protocol (184)	W30	MSS [Waveform

	(VHF-FM Military Tactical AJ)				Family]
W2	*HAVE QUICK II (UHF-AM/FM/PSK Military Tactical AJ)	W8	HF-ISB ALE	W32	BOWMAN (UK HF/UHF Military Tactical) [Waveform and Equipment Family]
W3	*UHF SATCOM Military (181-182-183 “DAMA”)	W9	HF-SSB ALE AJ		
W4	*EPLRS	W10	Link-11 / TADIL-A		
W5	*WNW	W11	STANAG 5066 (HF Message Protocol)		
W6	*Link 16 / TADIL-J	W12	STANAG 4529 (HF NB Modem)		
		W13	VHF-FM – Military Tactical		
		W14	HF ATC Data Link		
		W15	VHF-AM ATC		
		W16	VHF-AM ATC Extended		
		W17	VHF/UHF-FM LMR: (Land Mobile Radio & Public Safety w/ Project-25 and TETRA) [Waveform Family]		
		W18	VHF ATC Data Link (NEXCOM)		
		W19	UHF-AM/FM/PSK Military Tactical		
		W20	Link-4A / TADIL-C		
		W21	Link-11B / TADIL-B		
		W22	SATURN (UHF PSK AJ NATO)		
		W23	STANAG 4193 Mode S Level 4/5		
		W24	DWTS (UHF PSK WB LOS)		
		W25	Soldier Radio & WLAN & Advanced Capability [Waveform Family]		
		W26	COBRA		
		W27	MUOS-CAI (UHF SATCOM Military Obj.)		
		W28	Cellular Radio & PCS [Waveform Family]		
		W29	Link 22 / NILE		
		W31	IBS-M		
		W32	BOWMAN (VHF)		

The US Special Operations Command leads Cluster 2, which will adapt the current MBITR handheld radios to be compliant to the JTRS Software Communications Architecture (SCA). Cluster 2 includes the incorporation of programmable COMSEC and the APCO-25 waveform. It also includes the legacy military voice waveforms in the 30 - 512 MHz range.

Figure 2-30. JTRS Components for Cluster 1

Clusters 3 (Maritime/Fixed Station) and Cluster 4 (Airborne) has been combined into the single JTRS Airborne and Maritime/Fixed Station (AMF) program, managed jointly by the Air Force and Navy. The JTRS AMF program supports the DoD vision to create an Internet Protocol-based network that is an extension of the Global Information Grid (GIG). Gateway functions will be provided as needed to link legacy waveforms and new waveforms (i.e., support network centric operations for all the waveforms).

JTRS Cluster 4 will support airborne applications for fixed wing aircraft. The target customers for this cluster include the US Air Force and the US Navy. The Cluster 4 concept includes an open architecture, standard interface(s) that allow multiple JTR sets installed in a single aircraft to operate as a single entity for data exchange, and system control. This includes JTR radios developed in Cluster 1 as well as the MIDS JTR radio design, which was funded under a different contract for development. Cluster 4 supports a mixture of radio functions to be included in each airborne JTR dependent on the individual platform’s requirements. At the heart of this design approach is a radio set of the appropriate size to replace the current ARC-210 radio. ViaSat is participating in the MIDS-JTRS program and is part of the Northrop Grumman team that is bidding for the AMF program.

Cluster 5 will oversee the acquisition, development, and production of JTRS handheld and manpack units plus forms suitable for embedding in platforms requiring a Small Form Fit (SFF) radio for the 2 MHz to 2.5 GHz range. Single and multiple channel units will be developed. More information on the JTRS program and details on the cluster goals, capabilities schedules and programmatic information can be found at the JTRS website: http://jtrs.army.mil.

2.3. Task 4 - Analyzing Current Efforts for the Roadmap to MMDA

The early development programs for integrated communications systems laid a foundation for the software defined radios of tomorrow. From the early days of the ICNIA program, the lessons learned were continually applied to the next generation design. As each of these designs matured, the results from YF-22 were included in the F-22, RAH-66 Comanche, and Joint Strike Fighter.

2.3.1. JTRS Cluster 4, the Key to MMDA Implementation

A modular JTRS radio design must include commonality across form factors. This is at the heart of an airborne network that enables future capabilities and expansion of the Global Information Grid as illustrated in Figure 2-31. JTRS is not a legacy radio replacement. It is new functionality that supports network centric operations. The requirements need to be warfighter focused, providing the needed operational capability at the earliest opportunity. This suggests the use of spiral development and evolutionary approaches. The design must be forward looking and support the migration of airborne platform capabilities, thereby maximizing the capability to support these network-centric operations. Finally, this approach must be cost effective and leverage prior investments by accommodating platform interfaces where possible.

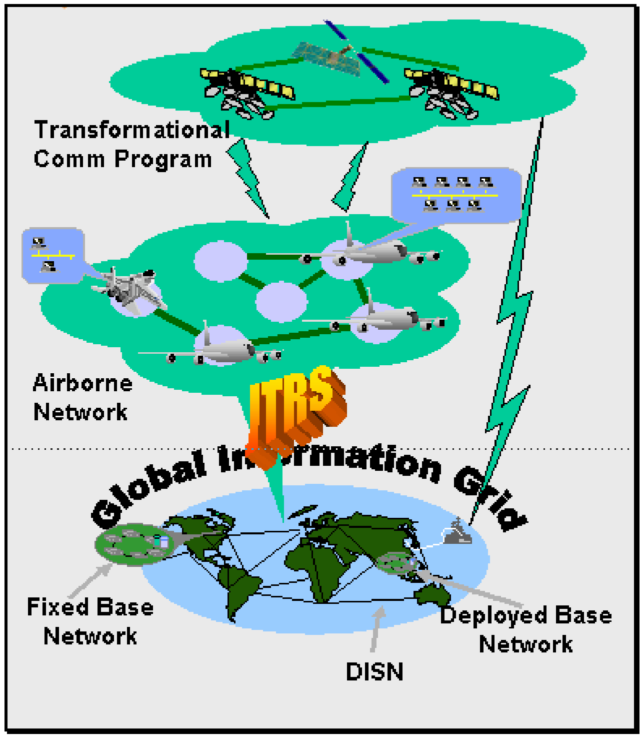

Figure 2-31. Airborne JTRS Vision

Implementation of JTRS requires a mixture of support for legacy systems and a transition to a network capability. Legacy capabilities must meet the replacement needs of airborne forces with a backwards-compatible design for existing radios. This will lead to a transitional capability that is backward compatible with existing radios. There also should be a forward-compatible enabling transition to network operations. This combination will lead to a network centric infrastructure for the airborne forces.

As stated earlier, key elements of the required approach include the development of a modular radio design with commonality across form factors. Early in the development cycle, the identification of platform interfaces that drive integration cost and complexity must be addressed. This leads to a single modular design capable to satisfy a full spectrum of platforms. Additionally, multiple sources of supply must be available to satisfy the demand and ensure price competition both today and in the future. The common hardware, open architecture approach fosters production economies and cost-effective sustainment of products. The presence of competition will foster innovative modular designs and price/risk mitigation. An important part of this approach is to develop a capability roadmap that ensures integration is leveraged for new JTRS functionality. This will enable network centric operations, which are the cornerstone approach to DoD's future communications.

A defined roadmap will not solve all problems in implementing airborne networks. Current protocols tuned for ground mobile and elevated nodes may not perform in high dynamic air-to-air situations. The defined airborne network is not hierarchical, less dense but geographically much larger, and will experience higher rates of change than today. This creates a need for more dynamic protocols. Airborne interference and dynamics create intermittent outages, which degrades performance. Network aware applications are needed to make the system more tolerant of intermittent outages. Waveform signaling must accommodate airborne co-site situations. Better frequency management and alternate routing over link types (diversity) is needed to increase airborne network availability. The airborne network must operate with heterogeneous links. These challenges are accentuated because the majority of aircraft lack a modern network infrastructure. Aircraft infrastructures that will accept network-capable radios need to be defined and developed.

Early efforts concentrated on developing an open standards-based networking approach that would allow connectivity and interoperability between JTRS and collated links like MP-CDL, FAB-T and Lasercom. Interoperability can be achieved through the use of standard layered, commercial network interfaces and protocols. This approach must also be evolutionary, addressing the users demand for an initial JTRS operational capability with migration to full network-centric communications. Developing and allocating requirements for a network initiative is essential to allow the evolution of hardware and systems to continue without creating significant future development risks and cost.

To combat design risks, a layered allocation of requirements between the platform/platform network and the JTRS radio set is needed. The users must accomplish the critical definition of platform network performance and standards compliance. Additionally, concepts for how to best incorporate a gateway/message format translation capability, either in JTRS or as an application layer, with a goal of connecting legacy systems into this future airborne network is being developed. This implies a migration towards JTRS implementation using advanced, commercially-based radio and network technologies where possible. The use of military specific systems is used only if more viable alternatives do not exist. Another key factor is planning for obsolescence by using a “layered” approach to the JTRS network architecture. In a layered view a radio is only one part of a complete, network centric communication system as illustrated in Figure 2-32. The radio implements only the lowest layers of the communication system. It can be likened to a device much like an Ethernet card or a phone line modem.

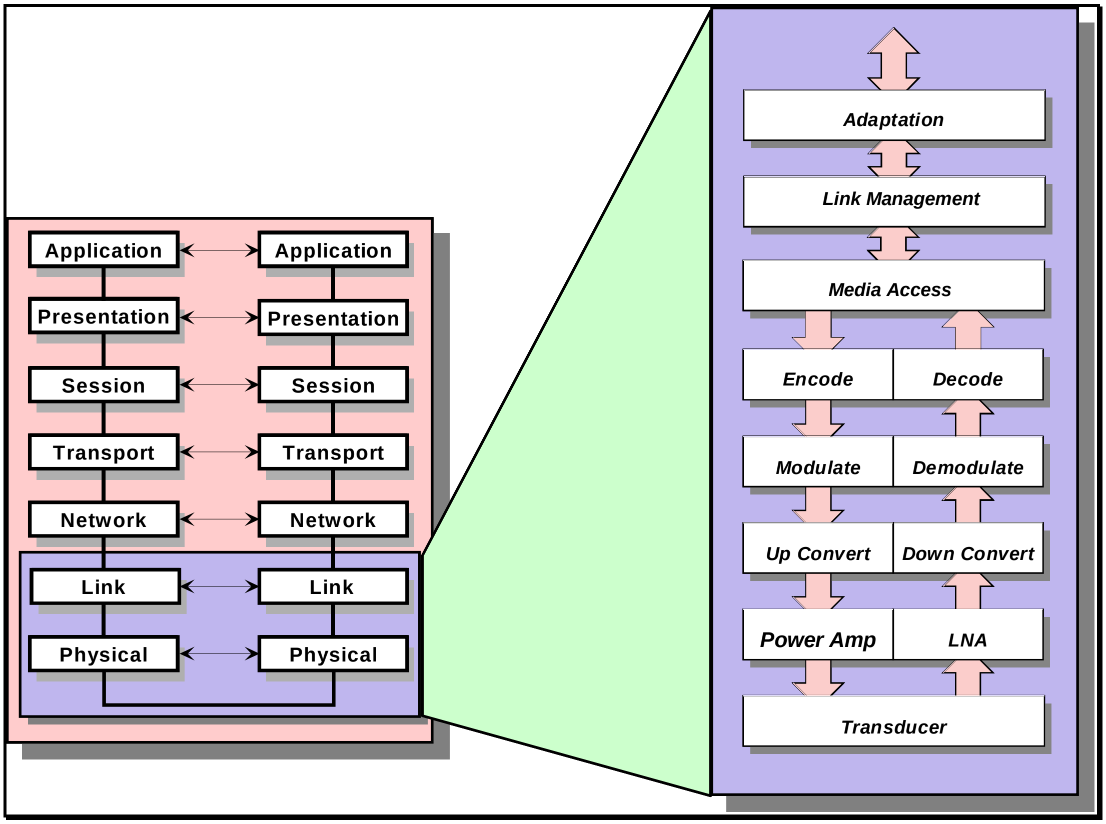

Figure 2-32. Layering Approach to Network Architecture

Layering is based on the proven commercial implementation of the Internet. It provides a level of flexibility allowing systems to evolve with fewer constraints. Additionally, it provides for future technologies to be introduced with relative ease, which makes the system more extensible. Implementation of a layered design philosophy based on commercial internetworking concepts is accomplished by adopting standard commercial interfaces. Finally, as illustrated in Figure 2-33, a bridge is created between COTS and DoD Links.

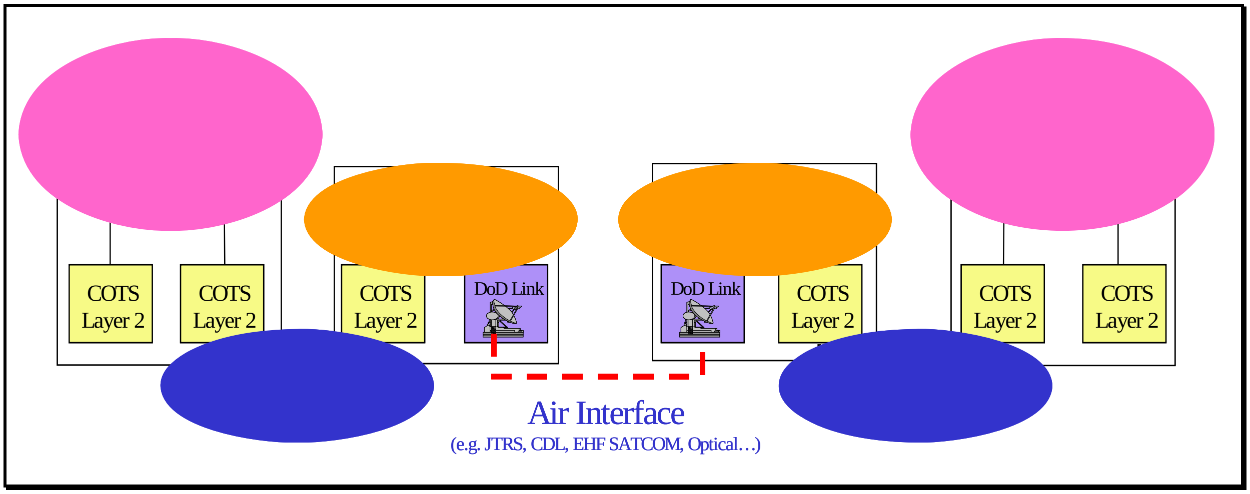

Figure 2-33. Layered Design Philosophy

2.3.2. Military JTRS Applicability to MMDA

The JTRS concept does not identify a particular implementation. It only requires that the software be portable and that all user and waveform application interfaces be common across all implementations. The use of a similar architectural implementation between like domains in the military and civil environments (e.g., airborne, vehicular) could result in benefits for both entities. The benefits are in terms of greatly reduced developmental cost to the civil avionics industry and greatly reduced non-recurring costs to the military procurement. These are a strong motivation to exploit the synergy between military and civil applications. One concern is that the highly capable, multifunctional, common elements that will needed for military JTRS may be too expensive for widespread use in the civil environment.

Some of the processing elements (RF and digital) must be capable of performing very complex functionalities over a broad spectrum of algorithms, frequencies, bandwidths and security levels. The functionality list for present and future civil avionics capabilities, while significant, is far less than that proposed for the military JTRS. An MMDA terminal design may have to add unique hardware and software to the presently conceived military JTRS architecture. On the other hand, most of the civil communication and navigation functionality identified for future civil aviation (e.g., Global Access Navigation Safety [GANS]) is compatible with the proposed the military JTRS architecture.

The following sections provide proposed architectural implementation designs for MMDA. The designs use either the proposed military JTRS architecture directly, with example functionality assignments, or a civil JTRS implementation that leverages from the military JTRS architecture but with modified capability elements (less complex). This approach results in a less costly design, while still deriving much of the non-recurring development from the military JTRS.

2.3.3. MMDA Implementation Using Tactical Airborne Domain JTRS Architecture

It is possible to use the JTRS Tactical Airborne Domain (military) proposed architecture “as is” for the base implementation of a civil CNS functionality. Figure 2-34 depicts such an implementation where an example waveform suit is implemented.

Using unique RF hardware is consistent with the JTRS architectural concept as each frequency band usually will have a tailored antenna interface unit to establish system performance in both receive and transmit. This includes the pre-selector (where most of the system NF and thus receive sensitivity) is established, RF band filtering, transmit/receive antenna switching, and transmitter final RF power amplifier. This “front-end” circuitry is frequency band driven and in some cases unique waveform driven.

JTRS will define the VHF/UHF communications band, UHF SATCOM, Wideband Network Waveforms (WNW), HF communications and other unique front-ends. Functions such as terminal data link (e.g., 802.11) and Inmarsat will need to be developed outside of the currently defined military JTRS implementation. This requirement results partially from the fact that the proposed common transceiver for the military JTRS provides RF processing capabilities from 2 MHz to 2 GHz. Waveforms operating outside this band will need to be added to interface to these transceivers. New front-end elements will not only provide the pre-selector and final PA functionality for the new frequency band, but also up or down frequency conversion as required. Again, this is consistent with the JTRS architectural concept.

Figure 2-35 adds the unique architecture elements required if a civil version of Link 16 were to be included in the MMDA terminal. The unique elements are the RF front-end and an unique fast frequency hopping receiver/exciter. This approach has been taken because including the specific Link 16 fast frequency capability (fast settling time synthesizer, etc) in the common transceiver would not be implementation efficient for the remaining JTRS architecture elements. Note that UAT would probably share the RF front-end LRU with Link 16, as its intended operational frequency is 978 MHz. UAT’s functions have generally similar media access, modulations and information bandwidths. Since one of Link 16’s hop frequencies is also at 978 MHz, scheduling coordination between the two functions would be needed. Co-site issues have to be considered as Link 16’s total frequency range is 969 MHz to 1213 MHz.

In both versions all the JTRS military architectural elements are being used as provided. However, the host interface will probably need to be tailored to fit civil applications. Also, the security module would be populated only with the security engines that would be needed by civil

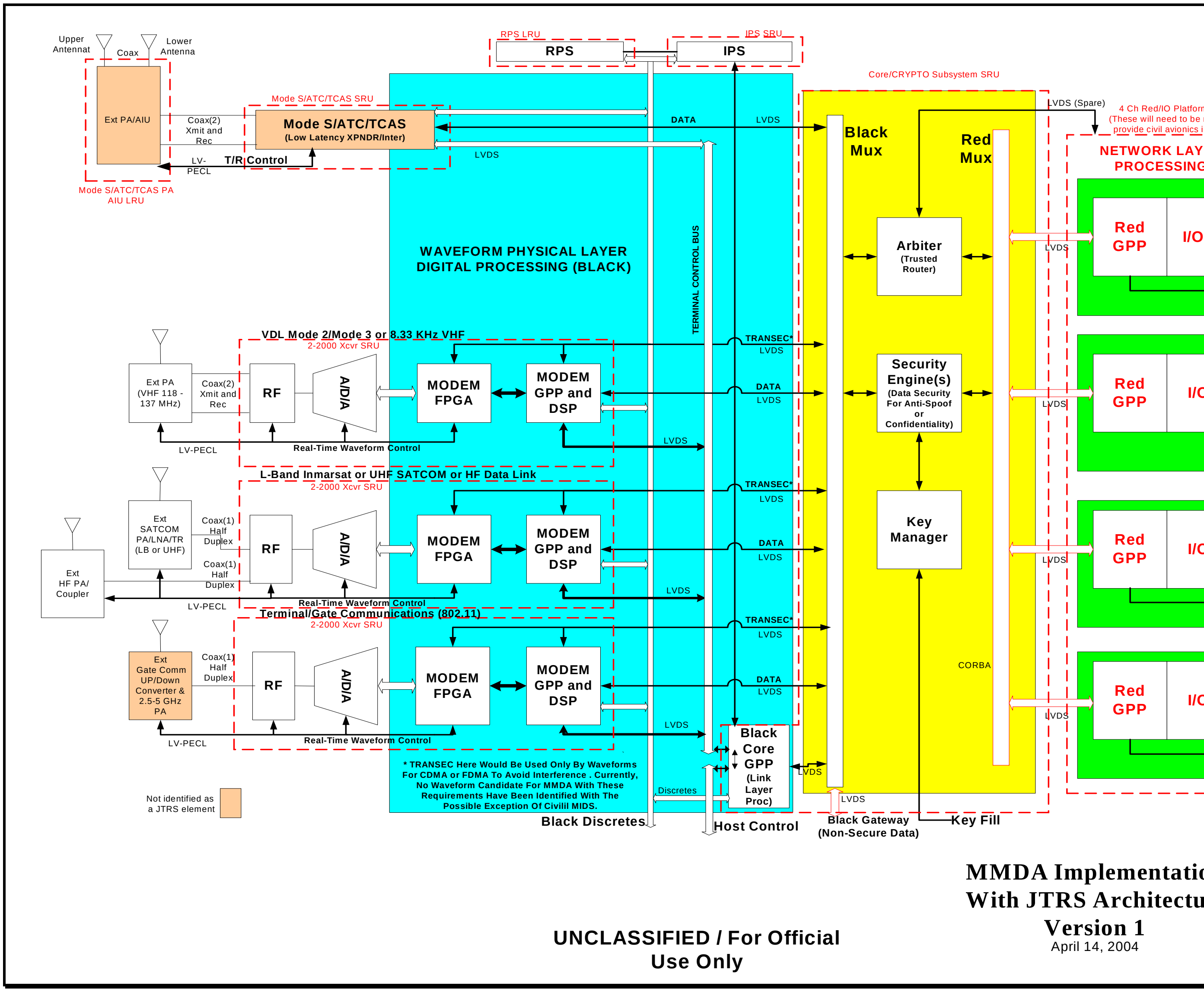

Figure 2-34. MMDA Application Using the JTRS Tactical Domain Architecture

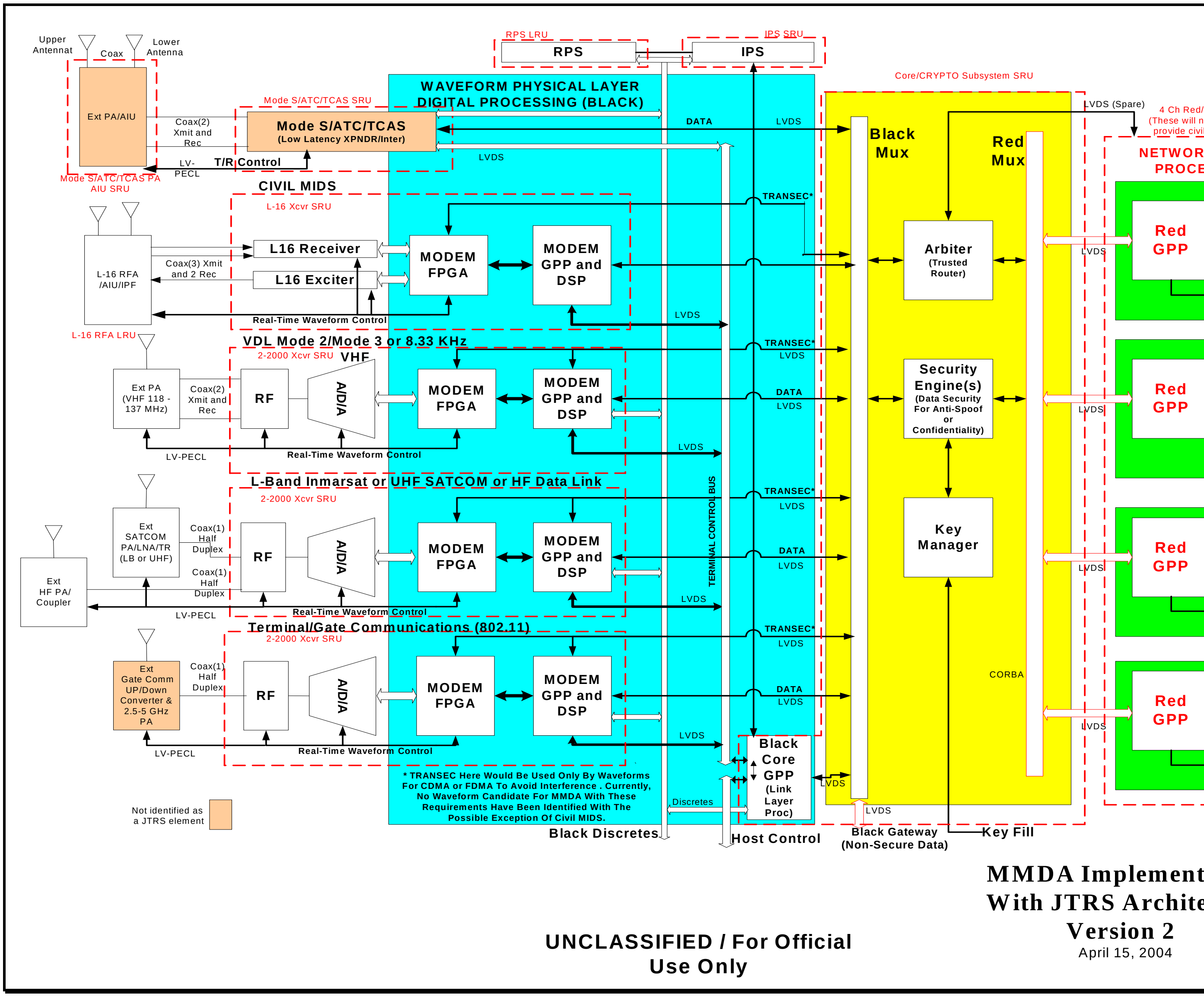

Figure 2-35. MMDA Application Using the Military JTRS Architecture with Civil Link 16

aviation to provide anti-spoof and anti-hijack capabilities. This should simplify the certification of this Shop Replaceable Unit (SRU) and the system as a whole. Finally, the illustrated architecture is configured for five simultaneous functions. Adding the appropriate RF front-end LRU, a transceiver SRU, and possibly another red GPP/IO SRU accommodate additional functions operating concurrently. (The existing Red GPP/IO may have enough spare capacity to accommodate an addition function.)

2.3.4. MMDA Implementation with a Civil Airborne Domain JTRS Architecture

The JTRS Tactical Domain design implementation is proposing a highly capable, multi-function, multi-mode transceiver that includes all the RF receiver/exciter functionality. It also has all the waveform real-time digital signal processing and resource control. The Core/Crypto SRU uses programmable embedded cryptographic engines and is capable of storing multiple red keys, compatible with the US Air Force's Electronic Key Management System (EKMS). It will be able to operate at Multiple Single Level Security (MSLS) processing level, as opposed to just system high. These capabilities may be an overkill for the civil application, increasing the certification risk/timeline and be cost prohibitive, especially for the small general aviation application. Therefore while there may be an interest to use as much as the JTRS Tactical Domain architecture implementation as practical to obtain the benefits of qualifying and certifying a common design, replication that is not cost effective for the civil application should be avoided. This is consistent with the basic JTRS concept of tailoring the implementation to the application domain, while maintaining the user interface and software common across all domains.

Thus, the following JTRS architecture is suggested for the Civil Airborne Domain. Figure 2-36 illustrates an architecture that retains the concept of the military Tactical Airborne Domain architecture implementation, but attempts to simplify some of the key processing elements to reduce complexity. This in turn should ease the certification process and reduce the cost of ownership. These modifications are described below.

2.3.5. Transceiver/Digital Signal Processing Modifications

The first suggested modification is the partitioning of the military JTRS proposed transceiver into a more traditional receiver/exciter transceiver (XCVR) SRU and a Digital Pre-Processor/Signal Processor (DPP/SP) SRU. The receiver would use either a direct conversion (DCR) or a "low IF" approach. The former uses a single conversion directly to baseband, while the latter is similar to a super-heterodyne. However, it has a low second IF that can be readily digitized in quadrature (required for any phase/frequency modulated signals) with inexpensive analog to digital converters. While the DCR is attractive in its simplicity, it does require the pre-selector to be more complex, presents potential instantaneous dynamic range concerns, and exhibits a DC offset problem caused by RF leakage in the baseband mixer. This results from the reference being the same frequency as the incoming RF. The latter needs further review to evaluate if this really is a less costly approach than a tradition super heterodyne approach that down converts the received RF to an analog base band signal that is then digitized in quadrature in the DPP/SP SRU.

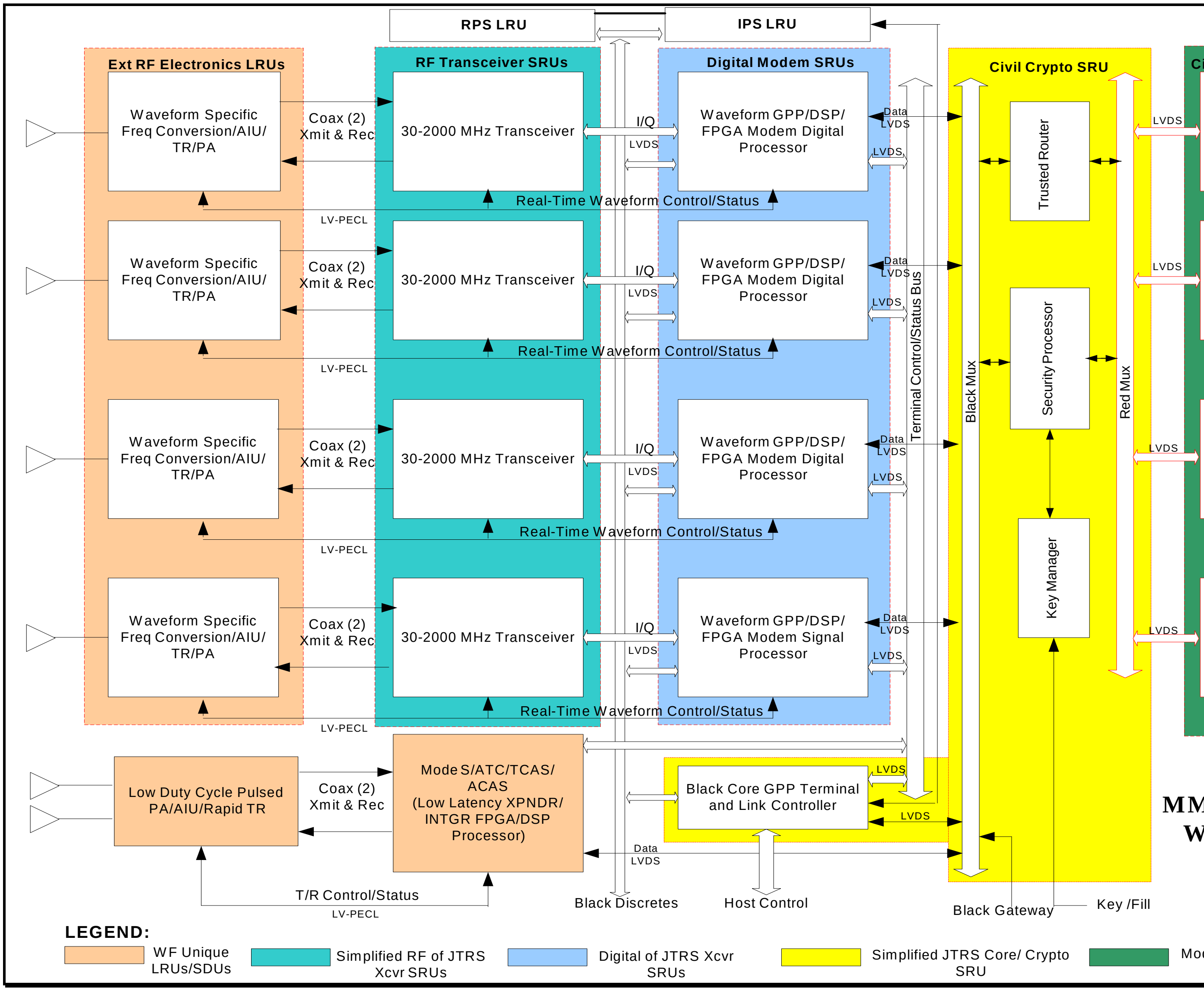

Figure 2-36. MMDA Implementation Using a Suggested Civil JTRS Architecture

The transmit chain of the transceiver consists of the Digital to Analog Conversion (DAC), if not already performed in the DPP/SP, up conversion to RF (with possible simultaneous final RF symbol modulation), and the required filtering. The band coverage would be limited to 30 MHz (or possibly 108 MHz) to 2000 MHz. This will cover all currently identified waveforms with the exception of HF communications (2 - 30 MHz) below and 802.11 gate link (2.5 to 5 GHz) above. Bandwidths will be limited to 24 MHz (possibly to 10 MHz), which should meet the civil requirements. This performance tailoring should result in a less complex, less risky and cheaper SRU.

The DPP/SP SRU will most likely carry over the military JTRS design with the additional interfaces to the transceiver SRU. The level and complexity of the civil waveform, especially VDL Modes 2/3/4 and Gatelink is consistent with those specified for military JTRS. Terminal management requirements remain basically unchanged from those of military JTRS. Therefore, throughput, memory requirements, latency requirements, etc. should remain unchanged. This is true also for the bus architecture, which would not be modified.

Separating processing capabilities that use very different technologies into two different SRUs should lower the complexity, risk and cost of each. The development of each SRU can be accomplished in parallel. The XCVR SRU can be developed, tested, qualified and certified independently from the DPP/SP SRU. Application software can be validated and certified on the DPP/SP without the need for the transceiver. Thus, RF developmental and certification problems will have far less impact on the digital hardware and application software development.

2.3.6. Security/Core Processor Modifications

The second consideration area for tactical JTRS modifications would be the security processing capabilities. The military JTRS waveform suite requires a large and extensive number of cryptographic security engines, extensive red key storage, and key management consistent with the EKMS. Also, it must be capable of MSLS operations. The features needed to provide anti-spoof and anti-hijack features for civil applications should be considerably less extensive. This modification could be as simple as removing and replacing much of the security engines capabilities, as well as reducing the key management to just that needed for civil aviation. Retaining much of the military JTRS security SRU overall design allows MMDA to receive the benefits of the certification required by the government for tempest, red/black isolation and anti-tamper. The core black GPP would be retained from JTRS to provide the front-end terminal management functions and the link layer processes (MAC and LLC sub-layers) for the data links.

2.3.7. Red Processor/Platform IO SRU

The last element in the JTRS architecture that needs to be modified is the platform interface SRU. This is necessary as the type and number of host platform interfaces for civil aviation is different than those being identified for JTRS's military applications. While the Red GPP capabilities could be retained for network protocol and transport processing, the interfaces to a FMU, CMU, pilot control and displays, etc. would be different than in the military application.

For example, current military aircraft use the MIL-STD-1553B interface for the avionics bus and future aircraft will use a Fiber Optic Channel for the primary avionics bus. Other buses are used for special interfaces such as RS-422 or MIL-STD-1394B to communicate with outboard LRUs such as intercoms or remote landing aids. JTRS has also specified the Ethernet interface, voice ports and a provision for discretes as identified by type. MMDA will need to identify the interfaces needed for civil aviation such as IEEE 429, X.25, and transponder discretes etc.

2.3.8. Future Growth Impacts

The Civil Domain Architecture may accommodate modest growth in simultaneous functionality with less cost impact than that of the Tactical Domain JTRS architecture. Only the appropriate front-end LRU and an additional XCVR SRU would be required (plus the application software) in the civil architecture. Provisions can be made in the initial design for the digital processing SRUs (i.e., DPP/SP) to provide sufficient spare processing capacity to accommodate the new function. However, this would most likely result in regression testing of any existing function that shared processors, buses, or memory with the new function. This would not be the case with dedicated elements assigned to each function or the additional functionality be provided with a new DPP/SP. Shared system busses may require limited regression testing, but analysis and computer modeling could satisfy this requirement.

2.4. Task 5 - Analysis of Past and Current Program Applicability

As a portion of the overall study effort, analysis of past and current programs was conducted to determine applicability of products, concepts, architectures and approaches to the MMDA system. Although the past (legacy) programs potentially affect the MMDA design, the JTRS program and its hardware and software architectures will have the most influence on the future design. Two key factors influence the overall results. They are determining the architectures or portions of architectures that will directly apply to the MMDA and determining which portions of the current JTRS products, architectures, or portions of architectures are not consistent with the design requirements of an MMDA radio.

2.4.1. Past Programs

The past programs analyzed met the criteria described in the introduction of the study. That is, they were multi-band and multi-functional. Additionally, the architectures that were examined were avionics that were held to the same stringent requirements that will apply to the deployment of an MMDA system. Flight hardware by nature has limitations on system size, weight, available aircraft power and available cooling. These factors all influence and impact flight hardware architectures. The critical nature of flight hardware coupled with the requirements for flight certification makes these legacy programs most influential on the MMDA architecture.

2.4.1.1. Integrated Communications Navigation Identification Avionics (ICNIA)

Beginning with the ICNIA program in 1983, the US Air Force has invested significant funding and engineering talent to develop a radio set with common assets and reusable software. These early programs, however, did not have the advantage of an SCA/CORBA based design approach. The ICNIA program was centered on common receiver and digital processing assets. The key performance requirements included the ability of the communications system to perform JTIDS and GPS functionality. These functions coupled with the critical timing required for secure Identification Friend of Foe (IFF) drove system timing, data throughput and encryption requirements.

The ICNIA program set out to provide re-configurable modules that were very adaptable to perform waveforms, encompassing a large list of frequency bands, bandwidths, gain characteristics, modulations, error control, anti-jam, data throughputs, security features, etc. In addition, nearly unlimited reconfigurability options were envisioned to promote fault tolerant designs such that multiple single point failures could be tolerated. All these goals were to be accomplished with a reduction in size, weight and power when compared to a suite of federated legacy radios. As the design development progressed, it became apparent that the technology of the day (early 1980s) could not support all these goals. Processing functionality was divided into more dedicated modules and some of the reconfigurability was reduced. While a 2 MHz to 2 GHz receiver design, a large RF switch matrix, and a VHSIC (Very High Speed Integrated Circuit) based multi-functional modem preprocessor (UMF) was carried forward to demonstration, signal, data and control processing was distributed to individual processors. Other separations included separate modulators and carrier generators that could be cross connected to UMFs and PAs to provide flexibility in the receive and processing chains, respectively. This architecture required several real-time proprietary buses that multiple waveforms shared and discrete interfaces with switching.

This architecture was able to demonstrate the feasibility of an integrated CNI architecture, but not without problems. The full band (2 to 2) receiver had difficulty meeting the full range of specification performance limits. A single receive design that could meet such a broad range of RF capabilities was very complex and expensive. A modem processor with the capabilities envisioned for the UMF was not fully realizable as a single module. Thus, signal processing was augmented with a special VHSIC signal processor. The result was distributed processing of individual waveforms across multiple processors, requiring strict timing and, sometimes, complex interfaces. The result did demonstrate waveform processing, but not with the design margins to ensure operation in extreme operating environments. Thus, availability shortcomings were observed.

The primary issues with this design approach revolved around hardware vs. software flexibility. As discussed earlier, although receivers and processors could be reconfigured, software reloading and control was difficult. The level of reconfiguration and flexibility in the system created significant software complexity and added additional tests for qualification. This increased performance risks. Reconfiguration also creates significant control software complexity. The amount of Built-in-Test and reconfiguration software required to run constantly within the system tended to load down processors. From a hardware perspective, the use of VHSIC and ASICs created significant upgrade risks. VHSIC devices could not be altered since they were provided designs from another government contract. The original ASICs designed for the program were extremely expensive to redesign or upgrade. Since ICNIA was a new design approach, hardware design modifications were needed to bring the design to compliance with performance specifications. This created a significant cost and schedule issue. In some cases ASICs were designed more than once in order to attain proper performance. This was an early indication of the need for a more programmable device during the initial prototyping and testing phases of a complex design.

2.4.1.2. F-22 Communications, Navigation Identification (CNI) and RAH-66 Comanche

Lessons learned from the initial development of the ICNIA system were applied in various ways to the F-22 design. Both the hardware and software architectures were modified, but more importantly new processes were invoked. The F-22 CNI program implemented first pass success criteria on engineers and applied the principal of Integrated Product Teams (IPTs) to balance the cost, risk and schedule of the system design. IPTs contained systems engineers, hardware engineers, software engineers, mechanical engineers and quality assurance personnel from the government, prime contractors and developers. This began with the development of the Prime Item Development Specification (PIDS) and continued through all of the systems engineering on the program. The theory was specifications and initial design risk reduction tasks would reduce or eliminate the need for multiple redesign cycles and allow cost and schedules to be met as proposed.

From a practical viewpoint this did not occur and design upgrades and the redesign of both hardware and software elements were required to meet performance specifications. The key element causing redesigns was early lack of interfaces and design data from other avionics subsystems that interfaced with the CNI system. This was especially the case for the program mandated Core Integrated Processor (CIP), which was required to be implemented by all the avionics sensors (EW, CNI, EO, etc.) A different subcontractor other than those who developed the avionics sensors developed the CIP. Late discovery of some processor performance shortfalls coupled with a lack of definition in some critical requirements forced many small redesign efforts that impacted the delivery of the system. Some design upgrades and corrections occurred after the initial software qualification process, causing significant regression testing to be required.

The F-22 leveraged off the ICNIA “Lessons Learned” to modify the architecture as follows:
The receiver design was partitioned into three optimal designs:

- VHF/UHF band receiver for CW signals (30 MHz to 400 MHz)
- L-Band single channel receiver for CW and pulsed signals (960 to 1800 MHz)
- L-Band multiple channel phase tracking receiver for pulsed interferometry (960 to 1215 MHz)

The UMF was divided into three optimized preprocessor types:

- Pulse Narrowband Preprocessor (PNP) for the NB VHF/UHF and IFF pulsed signals
- Spread spectrum preprocessor for the wideband signals like JTIDS
- Pulse environment AoA preprocessor to provide real-time interferometry

Reconfigurability was limited only to a subset of waveforms considered to be “mission critical” allowing the bulky and difficult switch matrices to be removed. This resulted in only 20 state configurations that needed to be tested and qualified instead of the over a 1,000 that would have been required to support the earlier vision of global reconfiguration. The concept of separate VHF/UHF CW and L-Band pulsed PAs was retained from ICNIA. However, it was recognized that power amplifier requirements for CW signals in L-Band required a separate design from that used for the pulsed application. Also, the carrier generator/exciter capability was included with the power amplification in a single module.

While separating the high speed processing into unique modules alleviated some of the ICNIA mutual interference problems, the common shared bus structure continued to cause “clogging” problems caused by subtle timing problems both in data and control. The result was that a signal functional waveform “miss-step” could cause the whole system to crash. Only after a long period of troubleshooting and analyses were these clichés reduced to an acceptable level to meet the mission profile (i.e., meeting availability specifications), but with little assurance margins.

The threaded software control structure that was implemented through major portions of the system did not allow for the use of an open bus structure. The buses employed were proprietary in nature and designed to the specific performance characteristics required by the prime item development specification. This fact alone excluded other participants from designing hardware that could meet the F-22 requirement. It also created additional technical and cost risk since the bus and interconnection structure was a new design and required prototyping and additional design and test to prove performance.

The software design resided on common executive and common kernel. This was a first step to a common software design similar to the required structure of SCA (prior to the adoption of SCA). The complexity of the software and the operating system was justified due to a requirement to operate the system in a multi-level secure environment. This is due to the fact that while multiple functions are operating within this radio simultaneously, they are not all operating at the same security level.

To mitigate software development risk, a common toolset was developed by Lockheed Martin and used by all of the major software suppliers supporting the F-22 development. The F-22 program used a single software development plan, conceived by Lockheed Martin and followed by all of the contractors. This included common development methodology, interfaces between contractors to discuss development and tool issues, and the interface of quality and configuration control personnel to ensure sharing of both successes and shortfalls.

One of the primary issues discussed earlier is limited reconfiguration. This was a cost and complexity trade. An attempt to qualify a significant number of cross connection paths for reconfiguration adds significant risk to a qualification program, especially when security is a primary issue.

The integration of this architecture was also a significant challenge. Small software bugs and performance shortfalls had a significant impact on the ability to test and integrate the system due to the threaded approach to control, functions sharing processors, and functions distributed across multiple processors. Software dominated the architecture and the performance of software embedded in processors became a pacing issue in qualification of both the software and the system. As stated earlier, the threaded control structure created bus contention issues, causing the system software to freeze. This caused the need to constantly reboot the system until these contentions were investigated and fixed.

A simple lesson learned is to balance the hardware portions of the system with the software. More simply stated "build the portions of the system in hardware or firmware where functions and algorithms are unlikely to change". In theory this will work well if you do not have to redesign key elements of the hardware too often. As in the case of the ICNIA system, both the F-22 and RAH-66 experienced significant redesign of ASICs causing cost overruns and schedule delays. Most of the redesign issues were not surfaced until the integration and test phase of the program.

2.4.1.3. F-35 Joint Strike Fighter Communications, Navigation Identification (CNI)

The first key lesson learned in F-22 and Comanche involved changing the design process. The process change was initiated by the manner in which the requirements were levied on the developer. Instead of the PIDS which provides design guidance specifics to the developer, requirements were controlled by a Performance Based Specification (PBS). The PBS only provides end-to-end operational performance from the user view point.

This resulted in a more efficient contractual interface between the developer, the host prime and the government. Design specifics and methods were left to the developer, but requirements were jointly controlled between the developer and the prime using the DOORS data base traceability tool. The first pass success approach used early in the F-22 project was abandoned for an iterative design process that included multiple hardware and software builds and prototyping followed by multiple test and evaluation cycles. This allowed design flaws to be corrected and newly discovered requirements to be implemented prior to final design and qualification. Using SCA software approaches and a more open architecture for hardware will allow multiple iterations to be implemented in a way that allows maturity of the system to be improved prior to critical qualification and certification testing.

The JSF F-35 architecture has used the advances in processing technology (over that used by the F-22 10 years earlier) to remove some of the difficulties encountered on F-22. RF minimization allowed the external bulky Antenna Interface Units (AIU) to be replaced by pre-selector/AIU LRMs for each frequency band (L&UV). Multiple receiver and carrier generator designs were reduced to single or dual transceivers LRMs. Unique functionality like GPS and IFF were assigned special modules rather than spread their specific (and sometimes complex/costly) requirements to all the common processing resources. Due to its relative simplicity, the entire transponder function was imbedded in the L-Band pre-selector/AIU LRM, rather than use a full multi-function, multi-mode re-tunable transceiver. Similar to the JTRS implementation, the specific power amplifiers for final transmit RF amplification are being provided as separate PAs with imbedded T/R switching.

The greatest improvements resulted from the advances in high-speed analog-to-digital conversion, inexpensive high throughput processors, dense FPGAs and memory, and embedded cryptographic capabilities. This has allowed the early vision of a “Universal Matched Filter (UMF) in a single LRM to be finally realized. The low latency preprocessing and signal processing functions are performed with FPGAs supported by embedded DSPs. The data and control processing functions are performed in GPPs. Security processing is provided by programmable cryptographic devices embedded within the module. The Red/Black boundaries are established within the module. Transit across this boundary is controlled by a trusted gateway using privilege or multi-level security labels on messages.

Based on the F-22 program integration and test experience, lessons were learned that left the JSF with a goal that any functional operation within the system is to be deterministic in nature. Malfunctions or failures in one waveform will not affect any other in the system. This deterministic behavior is supported by time slotted access to processing assets such as FPGAs, DSPs and the General Purpose Processor (GPP). At least two totally independent waveform threads can be accommodated in a single module. Independence is important in that faults and troubleshooting of one waveform does not propagate to other waveforms. That is, the performing thread characteristics are deterministic onto themselves All modem processing contained within a module allows interfaces to be implemented with intra-module buses such as PCI, which are fast, low power and minimizes system cross talk. All control required for control of RF assets to support the waveform assigned to the processor are provided directly by that processor, with coordination with other processor modules (i.e., other waveforms) only if dictated by shared asset or cosite considerations

Overall, a separate GPP based module that also controls the CNI interface to the host platform provides terminal management in terms of resource allocations of waveforms to digital and RF assets and higher-level coordination. Its function is really that of a message router to and from the CNI terminal. Again, distribution of the messages are controlled by message privilege routing tables that are downloaded to the CNI terminal along with the application image load and security key splits during the avionics coordinated startup process

A major mechanical design change from F/A-22 and AH-64 was incorporated in F-35. The previous programs used SEM-E modules. This resulted in significant intra- and inter-module interfaces that increased the "mixing" of data and control traffic (as well as cross talk) among waveforms. The F-35 program adopted the 6U module format that is approximately 1.5 times that of a SEM-E. It provides the real estate for the multiple levels of processing and Red/Black partitioning regions required. This allowed the implementation of the totally self-contained waveform processing and control module. It also reduced the complexity of the terminal interface backplane, which was a major problem in F/A-22.

The biggest problem with all the stages of waveform thread processing in a single module is not the throughput required but the removal of the heat generated when the processor is running anywhere near the maximum specification rates.

The goal for F-35 is to make the CNI JTRS compliant. However, there may be some instances where deviations from the standards will be requested and granted by the government. The deviations will most likely be driven by cost considerations to keep the program on schedule and to meet its platform performance requirements.

2.4.2. JTRS Applicability

JTRS is NOT an implementation standard, but establishes rules for common interfaces and portability of applications software across multiple implementations and across multiple user domains. JTRS implementations could benefit from the lessons learned in the evolution to the current F-35 design. If JTRS implementers do not consider what has been learned in the development of avionics capabilities with similar end goals, they will doom their programs to transgress through a similar decision maze. This does not need to happen. JTRS implementers need to take advantage of the mistakes and lessons learned from other earlier similar developments. Therefore, MMDA has the opportunity to direct its architecture implementation on lessons learned while remaining within the envelopes defined by the JTRS standards.

A summarization of the DoD objectives for JTRS is to develop a family of software defined, multi-band/multi-mode airborne radios that will be integrated into more than 65 platforms across all services. An evolutionary approach is preferred, providing initial JTRS capability early to meet user need dates and achieve full capability incrementally. The JTRS design will consider Total Cost of Ownership (TCO) including the impact of retrofitting aircraft. This implies a focus on ease of platform integration rather than just minimizing radio cost. Only through realization of a network-centric capability will the JTRS return on investment be maximized. This must be accomplished by enabling a network centric communications capability using the airborne network as an extension while maintaining current capabilities.

To support the overall program goals, early efforts concentrated on developing an open standards based networking approach that allows connectivity and interoperability between JTRS and current legacy radios. This is accomplished with standard layered, commercial network interfaces and protocols. The approach must be evolutionary addressing user demands for an initial JTRS operational capability with a migration path to full network centric communications.

Developing and allocating requirements for a network initiative is essential to allow the evolution of hardware and systems to continue without creating significant future development risks and cost. A layered allocation of requirements between the platform/platform network and the JTRS radio set should be applied. Another key factor is planning for obsolescence by using a “layered” approach to the JTRS network architecture. In a layered view a radio is only one part of a complete, network centric communication system. The radio implements only the lowest layers of the communication system. It can be likened to a device much like an Ethernet card or a phone line modem.

While most of the waveforms that appear on the JTRS implementation list provided in Table 2-4 represent legacy radios that do not meet current avionics standards, the new waveforms such as WNW and MSS will meet them by design. Others like Soldier Radio, COBRA, MOUS-CAI and Cellular Radio PCS meet some of the current standards. Many of the present digital communication link radios were designed to comply with MIL-STD-1750A (e.g., JTIDS/Link-16).

Currently, selective military radio systems address civil avionics standards that provide for non-interference with the civil aviation Air Traffic Control Radar Beacon System (ATCRBS) and Mode S system and communications in the VHF/UHF bands. For example, Link-16 must have an Interference Protection Feature (IPF) that protects the 1030/1090 MHz frequencies from spectrum contamination from high power JTIDS transmissions. Also, military VHF and UHF communications use similar channelization, selectivity, and adjacent-channel interference specifications as do civil aviation.

None of the commercial satellite systems (e.g., Inmarsat) are being directly addressed by any of the cluster developments. NASA GRC could play a helpful role in addressing these systems in future clusters.

The JTRS Technology Laboratory (Jtel), along with the Joint Interoperability Test Command (JITC) and the National Security Agency (NSA), will conduct a rigorous testing and certification program. Together, they will:

- Verify the compliance of each JTRS waveform and application with the SCA
- Verify the compliance of the Core Framework (operating environment) with the SCA
- Validate the functionality and accuracy or each waveform
- Verify compliance of each waveform with security requirements
- Assure the portability of each JTRS waveform across platforms
- Assure the interoperability of JTRS legacy waveforms

Jtel can be contacted at: http://jtel.spawar.navy.mil/aboutus.asp.

Relating the JTRS program goals to a commercial application will require the selective application of many of the JTRS goals, objectives and requirements. Since JTRS is being developed in an incremental fashion, the MMDA development schedule needs to be examined to determine if there is sufficient alignment for key requirements to be incorporated in the commercial design. Without schedule alignment two options will exist. One, realign the MMDA schedule to take maximum advantage of the JTRS development or two, align only those goals, objectives and requirements that align with the schedule. If the same layered architecture approach is implemented on MMDA, then future upgrades to the radio should present minimum design, integration and certification challenges.

There is a shortfall in applying the MMDA approach in commercial environment that may try to implement, voice, data and data link covering a wider frequency band than the current JTRS radios. The exception to this rule is the MIDS JTRS program, which is implementing Link 16 data link, navigation, and another channel for voice or other data. This design has more commonality with MMDA than other JTRS radios. The architectural implementation provides key data even if a commercial version of Link 16 is not used in this design.

The analysis and concepts included in this report shows the JTRS architectural concept would meet civil avionics standards. In fact, commercial aviation is mentioned in the JTRS vision statement as part of the “JTRS’ Technology Strategy-Implications Beyond The Battlefield”. Examples of these implementations for civil waveforms were presented and tailored for the commercial market in this report. It should be noted that these implementation concepts still need additional development to address many of the key mechanical, EMI and installation issues that face avionics.

2.4.3. Analysis and Assessment of JTRS Applicability

JTRS architectural goals are quite consistent with the goals for future civil avionics developments. In particular, the goals stated in ARINC 660A, and summarized below, and cross referenced in Table 2-5 are consistent with the JTRS vision.

- Architectures specifically to reduce software modification costs and software development time
- Architectures intended to enable incremental upgrades and incremental software approvals
- Architectures that reduce avionics acquisition and life cycle costs
- Flexible software revisions
- Fleet commonality-significant cost reductions achieved when a large degree of software commonality is achieved across multiple flight types (i.e., portability across multiple user domains)
- Avionics systems growth capability. CNS/ATM equipment must provide built-in growth capacity to accommodate and support the anticipated full CNS/ATM function set.
- Open system architecture that is free from propriety constraints. Ensure supplier competition by defining standards for individual components and functions, plus requiring interoperability and common operating procedures.
- Open system architecture that allows for sufficient functional independence; i.e., update, modify or add functionality with minimal impact on other systems. Partitioning should segregate hardware and software into logical and manageable entities, providing sufficient isolation such that changes within a partition or additions of new partitions do not affect the other partitions. This approach allows a step-by-step implementation and a reduction in overall cost by significantly reducing the risk of regression of the unaffected partitions.
- Need to ensure end-to-end integrity of data link applications and interoperability
- High reliability and availability provided by fault tolerant designs and redundant configurations
- Maintainability that facilitates simplified line and shop maintenance

Table 2-4. JTRS and Legacy Integrated Avionics Applicability to ARINC 660A

Summarized ARINC 660A Requirement Number	Architectural Requirement Topic	Sections Where Discussed in Report
1	Reduced Software Modification Cost and Development Time	1.2, 2.1.1, 2.2.6, 2.2.7, 2.2.8, 2.2.9, 2.2.10
2	Incremental Upgrades and Software Approvals	1.2, 2.1.1, 2.2.6, 2.2.7, 2.2.8, 2.2.9, 2.2.10
3	Reduce Acquisition and Life Cycle Costs	1.2, 2.1.1, 2.2.8, 2.2.9, 2.2.10, 2.4.2
4	Flexible Software Revisions	1.2, 2.2.6, 2.2.7, 2.2.8, 2.2.9, 2.2.10, 2.4.2
5	Software Commonality	1.2, 2.1.1, 2.2.6, 2.2.8, 2.2.9, 2.2.10, 2.3.1, 2.4.2
6	Systems Growth	2.1.1, 2.2.9, 2.2.10, 2.3.1, 2.3.8
7	Open System, Non-proprietary and Interoperability	2.1.1, 2.2.6, 2.2.9, 2.2.10, 2.3.1, 2.4.2
8	Functional Independence and Hardware & Software Partitioning	2.1.1, 2.2.3, 2.2.4, 2.2.5, 2.2.9, 2.2.10, 2.3.1, 2.3.4, 2.3.5, 0, 2.3.7, 2.4.1, 2.4.2
9	End-to-End Integrity and Interoperability	2.1.1, 2.2.9
10	High Reliability and Availability With Fault Tolerance and Redundant Reconfiguration	2.1.1, 2.2.3, 2.2.4, 2.2.5, 2.3.4, 2.3.5, 0, 2.3.7, 2.4.1.2, 2.4.1.3
11	Simplified Maintainability	2.1.1, 2.2.3, 2.2.4, 2.2.5, 2.3.4, 2.3.5, 0, 2.3.7, 2.4.1.2, 2.4.1.3

Table Key:

Requirements 1, 2 and 4 are being addressed by JTRS in its use of the CORBA middleware as discussed in Sections 1.2, and 2.2.7.

Requirements 1 through 5 are being addressed by JTRS with its application of the SCA as discussed in Sections 1.2, 2.2.8, 2.2.9 and 2.2.10.

Requirements 6, 7 and 8 were addressed in Sections 2.2.9, 2.2.10, and 2.3.1, with an example of logical and manageable hardware and software component partitioning (Req. 8) implementation provided in Section 2.3.4, 2.3.5, 0, and 2.3.7. Growth (Req. 6) was specifically addressed in Section 2.3.8.

Requirement 9 was addressed in Section 2.2.9

Requirements 10 and 11 were addressed in Sections 2.3.4, 2.3.5, and 2.3.7 and by the example of legacy implementations provided in Sections 2.4.1.2 and 2.4.1.3.

Sections 2.2.3, 2.2.4, and 2.2.5 provided discussions of legacy integrated avionics systems using logical hardware and software partitioning that provided fault tolerance and simplified maintenance.

Sections 2.2.6 through 2.2.9 provided discussions on industry’s Software Defined Radio (SDR).

Section 2.3.1 discusses JTRS airborne vision, while Sections 2.3.2, 2.3.3, 2.3.4, 2.3.5, 2.3.7 and 2.3.8 provides illustrations how the JTRS approach could be applied to satisfy 660A goals (i.e., MMDA).

Section 2.4.1 further describes on-going military integrated avionics developments, while Section 2.4.2 discusses JTRS applicability to MMDA as an ARINC 660A type development.

In addition, ARINC 664 Part 5 states that an off-board IP link capability is a reasonable possibility for any future network architecture, and that the ISD must be defined based on open computing and commercial network definitions to standardize its network environment.

Common network services and network management are required to enable use of common applications across mixed aircraft fleets. These requirements are consistent with the military’s goal of using the JTRS to provide a “network centric” capability into the battle environment. That is, provide an Internet-type access for all of the information that is made available by all the functional data links. Network centric philosophy for SDR and JTRS are discussed in Sections 2.2.8 and 2.3.1, respectively.

2.4.3.1. JTRS Waveforms and Architectures that Meet Current and Emerging Avionics Standards

The completed review of current JTRS waveforms indicates that a total of five waveforms are currently under contract applicable to civil aviation requirements. These waveforms will be certified for use on military aircraft flying in civil airspace and are directly applicable to a commercial MMDA radio. These waveforms include:

- HF ATC Data Link
- VHF-AM ATC
- VHF-AM ATC Extended
- VHF ATC Data Link (NEXCOM)
- STANAG 4193 Mode S Level 4/5

The JTRS program is not expected to meet civil aviation standards (RTCA or AEEC) in its hardware components, but is expected to meet civil aviation waveform functions. The characteristics of each waveform are described in Table 2-5. One waveform (VHF-AM ATC) covers voice communications, two (HF ATC Data Link and VHF ATC Data Link) are for data link communications, one is for navigation (VHF-AM ATC Extended), and for surveillance and identification (STANAG 4193 Mode S Level 4/5)

Table 2-5. Supported JTRS Waveform Characteristics

Waveform (Short ORD Name)	ORD ID	Frequency Band	Normal Channel Bandwidth	Information Voice and/or Data Rates	Criteria [and Comments in brackets][Latest Version of Documents Shall be Applied]
HF ATC Data Link	W14	(T) 2 - 30 MHz (O) 1.5 - 30 MHz	3 KHz	Voice (A) & Data 300, 600, 1200, 1800 Bps	Air Traffic Control (ATC). RTCA DO-265, ARINC 635-3 & -735-3, and FAA TSO-C31d compliant TDMA and FDMA. Objective to 1.5 MHz in compliance with STANAG-4203, QSTAG-733, et al. [Packet data.]
VHF-AM ATC	W15	(T) 118 - 137 MHz (O) 108 - 137 MHz	8.33 KHz [Includes 25 KHz]	Voice (A) 16 Kbps	Air Traffic Control (ATC). RTCA DO-186A & ARINC 716 compliant and NAS Architecture with future 108 - 118 MHz (presently VOR/ILS and emergency ATC voice). Navigation uses may require increased reliability and availability. Include legacy 25 KHz plus European 8.33 KHz. Includes VHF guards (121.5 & 123.0 MHz et al) & inband signals (ELT & SELCAL et al).
VHF-AM ATC Extended	W16	108 - 156 MHz	25 KHz	(T) Voice (A) (O) VOR/ILS Nav (A)	Air Traffic Control (ATC), VHF Omni-Range (VOR), and Instrument Landing System (ILS). QSTAG-706 & RTCA DO-186A & -195 & -196 & ARINC 716 complaint, and NAS Architecture with future 108 - 118 MHz (presently VOR/ILS and emergency ATC voice). Navigation uses may require increased reliability and availability. Includes extended legacy 25 KHz. Includes VHF guards (121.5 & 123.0 MHz et al) & inband signals (ELT & SELCAL et al).
VHF ATC Data Link (NEXCOM)	W18	118 - 137 MHz	25 KHz	Voice (D 4.8 Kbps) & Data 31.5 Kbps	RTCA DO-186A & -224A compliant, a.k.a. VDL 2 & 3. Next Generation Communication (NEXCOM) FUW FAA CONUS and overseas & military ATC.

Waveform (Short ORD Name)	ORD ID	Frequency Band	Normal Channel Bandwidth	Information Voice and/or Data Rates	Criteria [and Comments in brackets][Latest Version of Documents Shall be Applied]
STANAG 4193 Mode S Level 4/5	W23	1030 & 1090 MHz	3.5 MHz / 3 MHz	Data 689.7 Bps (1.45 μsec PCM) IFF Family, and 9.6 to 128 Kbps Mode S, plus others per Standards.	Fully compliant with STANAG 4193 including Mode Select (Mode S), Levels 5 & 4 lower. Threshold includes both transponder s and interrogators on platforms and at low transmit powers. Objective includes upgrade to high power (ground-based and airborne warning et al) interrogators. Includes Mark X & XIIA with all Identification Friend or Foe (IFF) and Selective Identification Feature (SIF) Modes 1 through 5 and A & C, and ACP-160 and ICAO Annex 10 compliance. Includes civil secondary Air Traffic Control Radar Beacon System (ATCRBS), Airborne Collision Avoidance System (ACAS) and Traffic Alert & Collision Avoidance Systems (TCAS), and Automated Dependent Surveillance-Addressable (ADS-A) and Broadcast (ADS-B) functionality. Includes supporting interface to GPS and other systems for flight navigation and timing data. ADS requires interface to SATCOM, VHF Data Link, and other alternate channels IAW platform capabilities and mission needs. Includes generation of, and detection and alarm on, emergency messages, including ATCRBS (7700 emergency, 7600 communication failure, et al) and special military (4X et al) codes.

Notes: T = Threshold O = Objective A = Analog D = Digital

The VHF ATC Data Link waveform has been defined by the NEXCOM program, but may be an open venue for NASA and FAA cooperation. The certification of these waveforms is discussed in section 2.4.3.3. The use of the DoD portable waveforms by civil aviation that mirrors DoD applications and architecture is discussed in section 2.4.3.2.

The commercialized architecture described in section 2.3.4 (MMDA Implementation with a Civil Airborne Domain JTRS Architecture) uses the current elements of the JTRS architecture including SCA software architecture and CORBA services to accomplish a commercial set of functions for a software defined radio. This architecture, however, requires additional cost/benefit and physical partitioning analysis to tailor it for the civil application.

2.4.3.2. Areas of Concern or Challenge where JTRS does not Address Civil Avionics Standards

As a result of the assessment, key areas of concern and challenges have been identified. First, the areas are listed and then discussed. Areas of concern or applying the JTRS to the civil use are identified as:

- What will the JTRS concept packaged for civil applications cost?
- Will civil aviation (air transport, business and general) adopt the software portability and standard open architecture concept of the JTRS as the means to achieve interoperability?
- Is there any FAA certification legacy that can be claimed upon completion of the military programs?
- Can the JTRS be developed to use ISO TP4/CLNP protocols of the currently defined ATN?
- Is the Multi-level Security concept with the JTRS useful to industry?
- Will the aviation community support and ask for development of an MMDA buyer’s standard (AEEC action) that includes the concepts of the JTRS but defines the form, fit, and function for an aircraft swappable item?

2.4.3.2.1. Cost of Civil Version of JTRS Concept

What will the JTRS Concept Packaged for Civil Applications Cost?

Discussion. Table 2-6 gives the ranges that civil aviation can be expected to pay for discrete radio related avionics. The costs shown are based upon the study team’s experience. Any installation, training or retrofit costs are separate.

One program element of JTRS has targeted the end system for the mobile user at a $200,000 price point. However, there is no assurance that this target will be achieved nor is the support cost known to be reasonable. It appears that meet the civil target price ranges with any of the military produced JTRS radio systems will be unlikely.

Table 2-6. General Cost Ranges for Radio Related Avionics

Category	Item Purchase Price Range ($)	Remarks
Air Transport (wide and narrow body)	Radio VHF AM: 30 – 50K CMU: 100 – 150K	Voice and Communications Management Unit (CMU) for data link (dual or triple redundancy is required)
Business Jet	Use same units as air transport	
Regional	Normally voice radio voice only 25 – 40K	CMU/Radio new offerings in the 30 – 50K range now available
General aviation – Upper End	1,000 – 3,000	
General Aviation	500 – 1,000	

The cost effectiveness of the JTRS approach is to package several radios within the same MMDA enclosure and thus yield a reduced amount of avionics equipage. The discrete radio package prices of Table 2-6 have to be compared to the aggregate cost of having a number of radio capabilities within the single JTRS. This is a function of the class of user and the number of radio related avionics normally carried. The analysis of these tradeoffs is beyond the scope of the current study. However, it is not apparent that a civil affordable unit will be produced within the military-led JTRS program. This means that any use of the JTRS architecture standards will require a new end system design effort – although this new design may reuse some of the current or expected JTRS components.

Recommendation. NASA should foster a "design to unit cost" analysis to be an integral work task for any prototype development project of a MMDA unit that will incorporate the JTRS approach. A step in this analysis will be to conduct a cost study to determine if a mix of integrated avionics and price point is justified.

2.4.3.2.2. Civil Aviation Adoption of JTRS

Will civil aviation (air transport, business and general aviation) adopt the software portability and standard open architecture concept of the JTRS as the means to achieve interoperability?

Discussion. The heart of interoperability in JTRS is based upon portable (standardized) waveforms. There is very little parallel in civil aviation for this vendor-to-vendor portability. However, two avionics related software components show that the civil industry may adopt a similar principle, provided the end product is reasonably priced. The examples are the Tactical Collision Avoidance System (TCAS) and the government-led Aeronautical Telecommunications Network (ATN) router program of the late 1990s. In each case the government supported software products that were then made available to all. The TCAS approach should be reviewed to determine how well the concept is working.

Recommendation. NASA should foster an industry activity to review the use of a common waveform concept and to foster government leadership in establishing the approach.

2.4.3.2.3. FAA Certification Legacy from Military Programs

Is there any FAA Certification Legacy that can be Claimed upon Completion of the Military Programs?

Discussion. This concern area is addressed in paragraph 2.4.3.3

2.4.3.2.4. JTRS and the ATN Protocols

Can the JTRS be developed to use ISO TP4/CLNP protocols of the currently defined ATN?

Discussion. Adding the International Organization for Standardization (ISO) protocols to the JTRS is a requirement if the adoption of the current ATN standards proceeds. It does not appear that military planners intend to add the Transport Protocol Class 4/Connectionless Network Protocol (TP4/CLNP) required by the ATN standards as the VHF ATC Data Link.

Recommendation. NASA should continue to foster the work to move the AEEC and International Civil Aviation Organization (ICAO) to adopt TCP/IP as the transport and network protocols for the aviation air-to-ground data links. If they are adopted, then ATN over IP will ease the use of a JTRS approach

2.4.3.2.5. JTRS Multi-Level Security Concept

Is the Multi-level Security concept with the JTRS useful to industry?

Discussion. The JTRS architecture makes use of information processing using multi-level security (MLS) and trust labels as the means to keep users and application data compartmented. The parallel in civil aviation is partitioning according to the critically of the flight information being handled. The software development for higher levels of flight critically is increasing rigorous. Use of the MLS may provide a technique to reduce cost, but would impose a scurity function on all processes. The technique would have to be introduced into all air traffic and airline information handling systems. This would be a large transformation to attempt.

Lastly, it is not clear if the government would release components and processes for general use. A “watered down” version of the concept may be required.

Recommendation. NASA should research this area to determine the potential benefits and to determine if the JTRS approaches to encryption and MLS have merit in the civilian environment.

2.4.3.2.6. MMDA Buyer’s Standard

Will the aviation community support and ask for development of an MMDA buyer’s standard that includes the concepts of the JTRS, but defines the form, fit, and function for an aircraft swappable item?

Discussion. There isn’t an on-going effort to adopt the JTRS architecture and waveform portability as a standard for civil avionics. The need to define the design considerations and certification guidelines for Integrated Modular Avionics (IMA) is being fulfilled by RTCA SC-200. Typically, the airline community will define a common “form, fit and function specification” for avionics units/functions that are considered to have common use across different aircraft types. This includes interface connectors. Through this standard process, the airlines improve strength in buying power as well the ability to use avionics on different aircraft types.

Recommendation. NASA should consider fostering a standards effort to include the definition of an avionics unit following the JTRS architecture and waveforms portability principles.

2.4.3.3. Certification Aspects Facing the Use of JTRS Waveforms and SCA Architecture in Civil Aviation

2.4.3.3.1. Background and Current JTRS Testing

The JTRS program has divided the testing, qualification and certification program into waveform testing and JTR Set testing. Each of the testing and certification aspects includes both a contractor/developer phase and a government phase. All testing accomplished on the JTRS program conforms to the uniform testing approach described in the Joint Test and Evaluation Master Plan. This plan outlines testing against core operational requirements and also discusses specific test and evaluation criteria for each individual waveform. Each cluster (physical/functional application) develops a test annex to address specific platform and operational requirements.

The Joint Interoperability Test Command provides testing for conformance and interoperability across all four services for all waveforms and platform applications. They represent the military version of the FAA with the added responsibility of certifying platform hardware and applications as well as the standalone waveform that resides in the government library. Additionally, the National Security Agency (NSA) provides testing and certification for compliance to security and INFOSEC requirements. The contractor phase of testing is divided into four distinct categories:

- SCA compliance
- In house testing and analysis
- Software Porting Readiness Review (PRR)
- Testing against representative hardware of the government's choosing

These tests are conducted per approved test plans and procedures and will usually be witnessed by government representatives from engineering and quality assurance activities. After this phase is completed and the government has accepted the results, the government phase of testing is initiated according to the following steps:

- SCA compliance
- Performance specification assessment
- Joint Interoperability Test Command (JITC) interoperability performance assessment
- NSA security assessment

–

Waveform testing is broken into specific events with these events requiring the participation of multiple organizations as illustrated in Figure 2-37. To prove portability of the waveform to multiple hardware platforms, the testing events outlined in Figure 2-38 must be accomplished.

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Completion of the government set of tests will then acknowledge the acceptance of the waveform for use in JTR set applications for operational functionality. The hardware/software and functional combination then require additional platform specific testing to obtain flight certification. The specifics of this phase are controlled by the Cluster manager and include:

- SCA compliance testing
- Performance specification assurance
- JITC interoperability testing
- Government field testing including NSA verification

JTR Set testing is broken into specific events with these events requiring the participation of multiple organizations as illustrated in Figure 2-39.

Waveform Development
Key: I: initiates, R: reviews, P: performs, C: contributes, A: approves, U: uses

Event	JTRS JPO	WF Developer	JTeL	Cluster/ Gov't PMO	JTR Set anftr.	System Integrator	JITC	NSA
JTRS Architecture &Requirements Validation	P				U	U		
WF Requirement Consolidation / Documentation	A	P/R	R/P		U	U	R	R
WF Architecture & Design	A	P	R		U	U		R
WF Code & Contractor Development Test	A	P	R		U	U		R
Formal Qualification Test / Porting Readiness Review	A	P	R	R	U	U		R
WF Check List	A	P	R					
JTRS WF Configuration Management	A		P					
WF Porting into JTeL WTE / Rep JTR Set	A	P	R					
Rerun FQT on Ported WF	A	P	R					
WF Portability Assessment	A	R	P		U	U		
SCA Compliance Testing	A	R	P		U	U		
Info. Assurance Testing	A	R	P		U	U		R
WF Quicklook Performance Assessment	A	R	P		U	U	R	
Recommend'ns Submitted to JTRS JPO	A	R	P				R	R
JTRS JPO Approval for JTRS WF Repository	P		C	U	U	U	C	C

Figure 2-37. Waveform Testing Events

JTRS SETS WITH PORTED WAVEFORMS
Key: I: initiates, R: reviews, P: performs, C: contributes, A: approves, U: uses

Event	JTRS JPO	WF Developer	JTeL	Cluster/ Gov't PMO	JTR Set Manftr.	System Integrator	JITC	NSA
Obtain WF from JTRS WF Repository	A		C	P		U		
WF Porting to JTR Set	R	C	R	A	C	P		
WF Integration Testing in JTR Set	R	C	R	A	C	P		
JITC Standards Conformance Testing	R	C	U	R	C	R	P	
JITC Legacy Systems Interoperability Testing	R	C	U	R	C	R	P	
NSA Security Verification Test		C	U	R	C	P		A
JTRS Set Software Configuration Management				A		P		R
JTRS Base WF Software Support (WF maintained in the JTRS WF Repository)	R	C	P					

Figure 2-38. JTRS Porting Events

JTR SET DEVELOPMENT
Key: I: initiates, R: reviews, P: performs, C: contributes, A: approves, U: uses

Event	JTRS JPO	WF Developer	JTeL	Cluster/ Gov't PMO	JTR Set Manftr.	System Integrator	JITC	NSA
JTR Set Requirements Consolidation & Documentation	R		C	A	P			
JTR Set Architecture, Design & Development	R		C	A	P			
JTR Set FQT and PQT	R			A	P			
JTR Set OE SCA Compliance Testing – Service Model OE-1	A		R	R	P	U		R
JTR Set OE SCA Compliance Testing – Service Model OE-2	A		R	R	P	U		R
JTR Set OE SCA Compliance Testing – Service Model OE-3	A		P	R	R	U		R
Target JTR Set Software Support				A		P		R

Figure 2-39. JTR Set Events

When analyzing all of the certification and qualification events required for JTRS waveforms, it becomes clear that only a few can be directly applied to the MMDA application. They include:

- SCA Compliance
- Waveform qualification approaches including:
  - Independence of hardware platform
  - Portability evaluation
- Security compliance as limited by civil aviation requirements

JTR Set compliance is not applicable to the MMDA approach since many of the platform specific requirements are significantly more complex and invoke higher standards than those required for commercial aviation. Although it is early in the JTRS development cycle, it does not appear that the civil aviation aspect of certification and qualification has been set as a requirement for either waveforms or JTR sets. The military and FAA are currently on separate but similar tracks for certification of software defined radios and the associated waveforms. This certainly may change over time as military officials consider requirements for operating within the civil aviation environment.

Furthermore, certification of waveforms or platform hardware on the JTRS program for a military application does not guarantee acceptance by the FAA. The JTRS approach of a government-owned waveform portable between hardware platforms is significantly different than the FAA view of qualification and certification of hardware and software for a particular functional application on a specific aircraft or class of aircraft. The FAA currently does not administer or operate an engineering entity that could be responsible for the repository of a waveform library. This implies the need for the FAA to accept the JTRS program certification and test only the application/platform specific portion of the system. This also would require a significant change in philosophy at the FAA and among many of the contractors now developing, building and qualifying systems for civil application.

2.4.3.3.2. Analysis of Certification Aspects

The open question not addressed in this assessment until now is: "Will DoD conform to FAA certification standards?" From analysis we see three potential program paths for civil portability of the JTRS waveforms and related hardware.

- NASA should foster and sponsor early support from the FAA to guide JTRS development to meet current and future FAA certification standards. This would involve development of the application software to meet the goals of RTCA DO-178B and development of the hardware to DO-254 standards.

- NASA should develop a bridge between DoD and the FAA certification process. This would entail allowing certain aspects of DoD's rigorous testing to meet or exceed FAA standards and establishing agreements with the FAA that such testing is acceptable. In addition, NASA should work to develop an agreeable plan to meet FAA certification requirements of those artifacts that do not comply with FAA standards. This would involve building a direct correlation between the DoD qualification methodology and the FAA certification policies. DoD and the FAA would have to agree that the middle ground is acceptable.

- Because of the projected costs of developing JTRS compliant hardware, NASA should establish a program to develop its own platform with the intent to amend certified MMDA hardware in civil aviation. In light of starting from scratch, waveform development and government ownership (either NASA or FAA) of the waveform would leverage the objectives of the JTRS program.

2.4.3.4. Working Groups and Key Individual Contacts Associated with Certification Aspects of Aircraft Equipped with JTRS Capability to Operate in FAA Controlled Airspace

The JTRS program office believes that JTRS has the potential to provide general aviation users with a low-cost, SCA-compliant capability for air and surface transmission of position, weather, traffic conditions, etc. with parameters akin to the capabilities to be provided by the Universal Access Transceiver. However to achieve this goal, civil aviation will have to adopt the SCA architecture through the RTCA, Inc. and FAA certification organizations. However, the JTRS program office only lists the FAA as a potential partner to work civil aviation issues.

At the time of the writing of this final report, there is no evidence that the FAA and the JTRS program office are working intimately to certify the designated Air Traffic Control waveforms.

2.4.3.5. Additional NASA Participation in JTRS

NASA GRC could play a significant role by participating in future cluster planning to insure that civil aviation needs and aviation concerns are adequately being addressed. Perhaps a future cluster could be specially directed towards the civil aviation domain. Many of the waveform applications would have already been developed and certified by the earlier cluster developments.

Establishing contacts with the JTRS Joint Program Office Cluster 1 Liaison (703-696-0478) [jtrs.cluster1@hqda.army.mil] would allow NASA GRC to closely track the IFF adjunct activity at Raytheon, as well as tracking the HF/VHF/UHF radio development for JTRS. AMF contacts are the JPO AMF Liaison office at (703-588-1198) [jtrs.amf@hqda.army.mil].

Cluster 5 will be responsible for developing the SATCOM capability for the military. Coordination with civil aviation would benefit by synergy with the military applications. Contacts for Cluster 5 are: JPO Cluster 5 Liaison office (703-588-1064) [jtrs.cluster5@hqda.army.mil]. Contact for the JTRS non-military initiative activity is: Director, JTRS Domestic Programs (703-588-0532) [jtrs.domestic@hqda.army.mil].

Formal negotiations can be initiated by submitting a letter of interest to the JTRS Joint Program Office, outlining the objectives, plan and participation desired.

2.4.4. Other Programs Providing Guidance and Lessons Learned

Other efforts where lessons learned, architecture or requirements that may be applicable to MMDA are summarized in the following paragraphs. Many of the suggestions, comments and design approaches discussed on these programs are similar to those of the major programs discussed earlier. It is important to note that studies, programs and approaches that considered similar architectures, attributes and requirements provide an even stronger argument for incorporation into the MMDA design.

2.4.4.1. MITRE View of SDR

In the MITRE view of SDR, there are two main operational flexibility goals for a software-defined radio. First, the “field configuration” goal allows the user to change the fundamental functionality of the radio to meet changing operational and environmental needs. This is a key issue, which must be reconciled with the FAA or other certifying agencies. The hardware and software may have the capability to be significantly reconfigured on the fly. The question is whether testing prove there are no impacts to other flight critical functions. Another key question to be answered is how far will the certifying agencies allow radios to be reconfigured.

Portability is defined as the ability to apply any set of radio modules up to and including an entire radio to any radio transceiver hardware implementation. To obtain these goals, the software to processor interfaces need to be defined without ambiguity. This implies defining the interfaces and keeping them stable. The functionality of services provided for applications needs to be defined, again without ambiguity.

MITRE also believes most current or currently envisioned commercial and government applications involve the movement of IP datagrams across a mixed network of wireless and land connections. The mobile network must have a capability to form sub-networks, underlying the larger overall network. This will include features like node entry and exit to the network, topology/architecture optimization, mobility and adjustment to mobility and adverse environmental factors and finally, network and spectrum management. The mobile sub-network is usually separated from a landline network by a security barrier. The level of encryption is based on the specific needs of the government or commercial application.

2.4.4.2. General Dynamics View of SDR

General Dynamic’s view of software radios focused on the use of CORBA within a military radio system. A critical issue with CORBA in a military or commercially secure environment centers on the ability to route data to any available processor. Security concerns make this a difficult certification process. Therefore, General Dynamics recommends CORBA real-time policy extensions to allow deterministic operation. This is possible through time-out and priority mechanisms not available with standard CORBA. These features include:

- Priority mapping
- Mutex interface for locking access to CORBA implementations
- Threadpools or processing lanes to prevent encroachment by other signal threads
- Private connection policies and invocation timeouts to provide a uniform method of specifying timeouts relative to connection failures

All of the features are required to implement the kind of security features required for a military or sensitive commercial application.

2.4.4.3. Rockwell Collins View of SDR

Rockwell's analysis of the SDR architecture shows a significant migration to digital technology. Digital functions have migrated from hardware implementation to VHDL applications. Inter-function communications have become standardized using CORBA, and data is repeatedly copied and moved because of operating system and middleware constructions.

These architectural changes although improving reuse, portability and standardization have created additional digital processing requirements, which increase the need for power and cooling. Power is an issue due to the limited battery life of handheld and small radios and because of the lack of power and cooling in most modern aircraft. This is a key consideration that must be addressed for the MMDA design to be flexible enough to be installed in commercial transport aircraft as well as smaller business jets.

Additionally, Rockwell considered the impact of standardized operating systems and architectures on the processing capability in a digitally based radio. Analysis of the changing core framework and operating systems may have limited benefit to software defined radios requiring very challenging round trip timing. If a core framework required zero MIPS, many runtime problems would still exist.

The most effective benefits may be obtained from changing the view of how things are done in the software world. CORBA data marshalling is a straightforward operation of data organization that has an opportunity for improvement in algorithms and sorting techniques. The SDR community of developers must support OMG in completing the definition of "Pluggable Protocol" so a high-speed inter-process interface can be implemented that is portable across platforms. ORBs and OSs should be developed based on a new paradigm where data is not moved up and down a protocol stack, but pointers are passed.

3. RECOMMENDATIONS

JTRS architectural goals are quite consistent with the goals for future civil avionics developments. In particular, the goals stated in ARINC 660A, are consistent with the JTRS vision. The architectural approaches discussed for a civil avionics version of JTRS contain the key hardware and software elements required to implement an MMDA approach consistent with the goals of software programmability and upgradeability with minimal impact on the basic hardware and system. This proposed architecture has an open bus structure and uses SCA/CORBA to define software interfaces, content and performance.

The JTRS architecture as applied to the civil aviation sector must be considered a functional architecture. The physical, installation and environmental requirements of the military sector would make this architecture much too expensive for direct application to the commercial world. The benefits of the new technology would not outweigh the cost, risk and scheduled implementation of the military world. Additionally, only five civil aviation applicable waveforms are being implemented in the JTRS program. JTRS may in the end, design and develop additional civil aviation-related waveforms, but in all likelihood commercial development will be required to meet a reasonable deployment schedule.

Software defined radios will provide an unique blend of hardware and software, facilitating higher levels of performance coupled with ease of upgradeability. The upgradeability and re-certification of the system is key to its economic benefit to users. As technology rapidly improves, will software radios suffer fates similar to those of more conventional systems? The answer will lie in how technology is applied.

Turnover, rollover, or upgrades in technology are generally thought to occur in cycles. RF technology rolls once every 7 - 15 years and digital technology is rolling in as little as 14 months. Digital technology upgrades usually include a significant increase in speed, throughput and memory. These performance improvements result in smaller hardware for avionics allowing more processing to be packaged in the available space. Although on a somewhat slower time scale, RF technology usually involves improved performance and miniaturization.

As discussed in section 2, digital technology is creeping into areas traditionally considered RF. Signal processing capabilities of DSPs have enabled many functions that were traditionally accomplished in hardware (i.e., analog) to now be accomplished using software. Digital technology is now used in the Intermediate Frequency (IF) portions of designs to accomplish RF band pass filtering, demodulation and RF to digital conversion. Powerful processors coupled with re-programmable FPGAs have enabled designers to continually improve algorithms, processing techniques and filtering techniques. Even RF receivers are using more digital technology for front end filtering and signal capture. Future digital processing applications may include final RF with implantation of analog-to-digital conversions taking place at the antenna. RF amplifiers will, however, remain analog for the foreseeable future.

Systems designers now have a wider range of products and techniques available to accomplish radio tasks. But how do you determine where to apply software and digital techniques? The answer involves a number of requirements that are magnified in avionics communications systems. First, size and weight play a critical factor in most avionics systems. Obviously, this impact is less in military transport or large commercial aircraft. Size and weight are critical to aircraft performance in fighter aircraft, business jets, commercial and civilian turboprop aircraft. In the military fixed wing sector like the F-22, every pound of avionics results in the need for 7 pounds of fuel to maintain flight dynamics.

Second, power and cooling go hand in hand. Many RF techniques include the use of passive filtering devices like capacitors and inductors. These analog receiver circuits are still more power efficient than a DSP processing band pass filter equations at very high speeds. In today’s digital world, speed and processing equal power and power creates a need for heat generation to be dissipated. Cooling needs to be applied to allow processors to maximize speed and to keep device temperatures at a reliable level.

The Joint Strike Fighter CNI program recently completed a number of key system architecture trade studies centered on how much processing and software could be used to accomplish CNI waveform processing. The final decision was based more on mechanical engineering requirements than processor and software capability. The system architecture initially proposed would not be reliable as cooling was not sufficient when the devices were operated near their maximum rated speed.

Finally, in the commercial world of MMDA another key factor looms on the horizon. Cost will dictate acceptance by the airlines, small commercial carriers and civilian pilots. Cost benefit analyses will determine if the improved technology is considered effective enough to implement. The concern is not just initial acquisition cost but also installation and aircraft modification costs, operational costs and upgradeability. With rapidly improving technologies available, many airlines are concerned about a never-ending cycle of new products that incorporate new capabilities but also create significant aircraft upgrade time.

Cost benefit analysis concentrates on how new technology will allow an airline to complete a route (deliver passengers and/or cargo). As an example, Category III ILS has the benefit of allowing aircraft to land in very poor visibility conditions. Airlines with this equipment do not have to re-route aircraft that encounter extremely foggy conditions. Therefore, the technology has a cost savings benefit associated with the acquisition and installation cost.

3.1. Overall Lessons Learned from Integrated Communications Programs Applied to MMDA Architecture

As the MMDA architecture is matured and physical, software and system interfaces established, the following lessons learned are used and applied to the final architecture. Lessons learned apply past solutions, past problems and an overall design philosophy to build a more cost effective, high performance software radio. Once again, the key to successfully implementing this architectural approach is an inherent flexibility allowing design requirement additions, problem fixes, and upgrades without significantly impacting the deployed design.

- Balance hardware and software in a software defined radio. There is no need to accomplish everything in software. Functionality that requires critical timing or other difficult performance parameters are unlikely to change and can be accomplished in hardware. FPGAs will give flexibility with high performance allowing design modifications without major impact to the hardware.

- Security dictates a large portion of the architecture’s partitioning. Even in a commercial application, anti-spoofing and anti-hijack will be a concern for air traffic control. The architecture’s flexibility and reconfigurability has to be built around the security requirements.

- FPGAs can replace ASICs until the design has matured and the market will warrant sufficient production to justify their use. Because of cost constraints and future upgradeability, FPGAs may become the logic hardware choice to allow upgrades and modifications without major hardware redesign.

- Avoid the use of threaded control throughout a system. Threaded control is a control structure that is implemented as a single level in the system touching every hardware device and requiring updating at every clock cycle. This significantly complicates software, reduces reliability and complicates certification testing. Threaded control must be carefully time-coordinated. Any performance shortfalls or failures will result in the loss of that function. Avoid control that must interface with too many pieces of hardware at a single time. High-level control messages from the data processor that trigger lower level embedded control, as envisioned for F-35 CNI, will eliminate many timing issues Finally, control must take into account that CNI functions tend to be asynchronous.

- Hosting multiple functions on processors (i.e., multi-tasking of a processor) causes significant complexity unless absolute independence can be established. The first rule of thumb is to try and keep processor loading at or below specifications, preferably at no more than 75% of the maximum specifications. If the design requires multiple functions on a single processor due to cost and weight considerations, then establish truly independent software objects that reside on that processor. Consider reloading images as functions change or reconfiguration dictates a change. Multiple functions create multiple integration issues. Real time simultaneous functions are needed and software certification complexity increases significantly with each added block of functionality hosted. Establishing deterministic independence for each waveform must be a high level goal.

- Spreading a single function across multiple processors limits performance, increases complexity, and adds test and qualification risk to the system. Independent functionality will require independent software modules. If multiple processors are required to complete functionality, then clean well-defined functional, testable and independent interfaces need to be established to ensure software performance and timing. Issues can be addressed without having to rewrite or debug the entire software package.

- The design and objective of CORBA makes it a virtual patch panel. In theory, software applications and data can be cross-connected in almost infinite number of combinations and permutations. There are two major reasons CORBA cross connecting must be limited. First, multi-level security will dictate separation of data and second, endless combinations will cause endless testing for certification if not limited by privileged routing tables or other types of interconnection restrictions.

- Designing with CORBA will require the use of extensions to implement security. These extensions are in the form of limiting what data can be connected to what processing element within the design. This assures that multiple functions with different security levels can operate simultaneously in the same system without compromising the security levels of any function.

- The MMDA process architecture should consider a layered approach. The radio implements only the lowest layers of the communication system. It can be likened to a device much like an Ethernet card or a phone line modem. Layering is based on the proven commercial implementation of the Internet. It provides a level of flexibility allowing systems to evolve with fewer constraints. Additionally, it provides for future technologies to be introduced with relative ease making the system more extensible. Implementation of a layered design philosophy based on commercial internetworking is accomplished by adopting standard commercial interfaces.

- A CORBA implementation does have some performance issues associated with data marshalling. It is recommended that the data marshalling function, which is very straightforward, be changed slightly. Instead of moving data up and down the protocol stack, move data pointers. This will allow large blocks of data to be used in more efficient periods of time.

- Implement a “field configuration” goal that allows the user to change the fundamental functionality of the radio to meet changing operational and/or environmental needs. To achieve this goal, the software to hardware processor interfaces need to be defined without ambiguity. This implies defining the interfaces and keeping them stable. The functionality of services provided for applications needs to be defined, again without ambiguity.

- Since most of the future applications will be more data intensive, a significant increase in bandwidth is highly desirable. This can be a significant issue since the available spectrum, which is partitioned into smaller frequency blocks, is heavily used. The following approaches can be considered to address these challenges:
  - Higher order modulations
  - The addition of spatial diversity, known as directional antennas
  - Use smaller portions or chunks in the unused or underused spectrum, creating the equivalent of a single broadband channel Orthogonal Frequency Diversity Multiplex (OFDM)
  - The utilization of time diversity through techniques like Time Division Multiple Access (TDMA)
  - The utilization of code diversity through techniques like Code Division Multiple Access (CDMA)

3.2. Conclusions and Further Studies

3.2.1. Introduction

The assessment of the applicability of the JTRS programs deliverables to the civil aviation market has involved the study and review of:

- The technology legacy and design consideration of the last 20 years in approaching interoperability based upon the techniques of the “software defined radio” (SDR)
- The understanding of the results achieved by several generations of government program efforts directed towards producing the SDR
- The consideration of civil avionics CNS architectures and possible directions in thinking how to proceed with the further study of the use of MMDA for commercial avionics
- The possible approaches for use of the JTRS to support the civil waveforms.
- Consideration of use of the security approaches of the JTRS but conformed for civil use

- The status of the current military program
- The testing activities associated with the delivery of the JTRS radio products
- A draft architecture approach to a civil JTRS prototype

As a result of performing these tasks, the study team derived a set of conclusions or recommendations. The summary of these conclusions and recommendations is provided for consideration by the NASA GRC leadership.

The conclusions are condensed to three major areas. The first area deals with the further research and development investment is technology and product development. The second area deals with the activities that must be also supported in the aviation community if the investment in the R&D is to be realized. The third includes an extended effort to understand the paths to certification either through the military program office or by work through the prototype project.

3.2.2. Area 1 Conclusions/Recommendation

Recommendation. NASA should proceed with a one of the MMDA prototypes being based upon the JTRS technical approaches.

Discussion. The open SCA architecture is a proven approach and there is a proven technology legacy that can be used to reduce risk and thus, capitalize upon the past.

Corollary Statements

- The work on a civil prototype based upon the JTRS approaches must include a parallel effort cost analysis activity to understand the target purchase and the life cycle support prices that the market will accept.
- The prototype developer must be required to include a design to cost analysis as part of any prototype. This analysis should show how the market target prices can be achieved in the timeframe of a development and initial operating capability.
- The prototype must be required to show a path to FAA certification. Insight to the minimum set of tasks that should be included is expected to be provided by a separate study. In is strongly recommended that if the R&D funding allows any waveform development should conform to RTCA's DO-178 practices and may include use of DER audits.

3.2.3. Area 2 Conclusions/Recommendation

Recommendation. NASA must start now to foster an aviation industry standardization activity that will be part of the process of gaining community consensus on a deployable

MMDA based upon the JTRS approach – or another set of architecture principles. This must be stared now in order to ensure a readiness to accept the use of a common set of principles.

Discussion. Efforts to gain industry acceptance on any common use standards can be a process requiring 5 to 10 years. In this case, the effort to development consensus standards for MMDA will be aided by the work currently under way in RTCA SC-200 and by the previous work under the SDR Group. The specific work to be considered is:

- Establish an industry approach to waveform portability
- Standardize the form, fit and function for the SDR including the SCA architecture within the aviation community

3.2.4. Area 3 Conclusions/Recommendation

Recommendation. NASA should resolve the path to certification issues with the JTRS Program.

Discussion. The government discussion to determine if there is a path for achieving FAA certification through the developers of the JTRS components should be initiated. NASA has the stature to make these inquiries. The first question is to determine if the waveform software development to be performed by the DoD contractors can conform to DO-178 practices. If not, NASA should consider making this part of the ACAST MMDA R&D efforts. Other FAA certification efforts of the JTRS hardware first require resolution of acquisition cost concerns.

Appendix A. Acronyms

Acronym	Meaning
AADL	Avionics Architecture Description Language
AC	Advisory Circular
ACAS	Airborne Collision Avoidance System
ACAST	Advanced Communications, Navigation and Surveillance Architectures and System Technologies
ADC	Analog/Digital Conversion
ADS-B	Automatic Dependent Surveillance – Broadcast
AEEC	Airlines Electronic Engineering Committee
AIAA	American Institute of Aeronautics and Astronautics
AIC	Aeronautical Information Circular
AMF	Airborne Maritime/Fixed Station
AMJ	Advisory Material Joint
ANS	American National Standards
AOA	Angle of Arrival
APEX	Application/Executive
API	Application Program Interface
ASICS	Application Specific Integrated Circuits
ATC	Air Traffic Control
ATCRBS	Air Traffic Control Transponder
ATM	Air Traffic Management
BIT	Build in Test
BIU	Bus Interface Units
CARERI	Chinese Aeronautical Radio Electronics Research Institute
CCM	CORBA Component Model
CDS	Cockpit Display
CIP	Common Integrated Processor
CMU	Communications Management Unit
CNI	Communications, Navigation Identification
CNS	Communications, Navigation and Surveillance
CORBA	Common Object Request Broker Architecture
COTS	Commercial Off-the-Shelf
CSRG	Common Standards Revision Group
DCR	Direct Conversion Receiver
DME	Distance Measuring Equipment
DMR	Digital Modular Radio
DoD	Department of Defense
DPP/SP	Digital Pre-processor/Signal Processor
DSP	Digital Signal Processor
DTC	Domain Technology Committee

Appendix A. Acronyms

Acronym	Meaning
DTF	Domain Task Force
EKMS	Electronic Key Management System
EMD	Engineering and Manufacturing Development
EUROCAE	European Organization for Civil Aviation Equipment
EW	Electronic Warfare
FAA	Federal Aviation Administration
FMU	Flight Management Unit
FPGA	Field Programmable Gate Arrays
FRAC	Final Review and Comment
GASIF	Generic Aircraft-Store Interface Framework
GAMA	General Aviation Manufacturers Association
GANS	Global Aeronautical Navigation System
GBAS	Ground Based Augmentation Systems
GIG	Global Information Grid
GNLU	Global Navigation and Landing Unit
GNSS	Global Navigation Satellite System
GOA	Generic Open Architecture
GOAA	General Open Avionics Architecture
GPP	General Purpose Processor
GPS	Global Positioning System
GPU	General Processing Unit
GRC	Glenn Research Center
HAIPE	High Assurance Internet Protocol Encryptor
HAIPIS	High Assurance Internet Protocol Interoperability System
HF	High frequency
HOL	High-Order Language
ICAO	International Civil Aviation Organization
ICNIA	Integrated Communications Navigation Identification Avionics
ICT	Information and Communication Technologies
IEC	International Electrotechnical Commission
IEEE	Institute for Electrical and Electronic Engineers
IFF	Identification Friend or Foe
ILS	Instrumented Landing System
IMA	Integrated Modular Avionics
INFOSEC	Information Security
ISA	Instruction Set Architecture
ISO	International Standards Organization

Appendix A. Acronyms

Acronym	Meaning
ISS	Integrated Surveillance System
IT	Information Technology
JAA	Joint Aviation Authorities
JTC	Joint Technical Committee
JTIDS	Joint Tactical Information Distribution System
JTRS	Joint Tactical Radio System
LLC	Land Component/Landing Command and Control
LRM	Line Replaceable Modules
LRU	Line Replaceable Units
LTPB	Linear Token-Passing Bus
MAC	Media Access Control
MDR	Multimode Digital Radio
MLS	Microwave Landing System
MLS	Multi-Level Security
MMDA	Multi-function, Multi-mode Digital Avionics
MMR	Multi-Mode Receiver
MOPS	Minimum Operational Performance Standards
MSLS	Multiple Single Level Security
NAP	Network Architecture Philosophy
NAS	National Airspace System
NASA	National Aeronautics & Space Administration
OEP	Operational Evolution Plan
OFDM	Orthogonal Frequency Division Multiplex
OMG	Object Management Group
ORB	Object Request Broker
O/S	Operating System
OSA	Open System Architecture
OSI	Open Systems Interconnection
PA	Power Amplifier
PASC	Portable Application Standards Committee
PDU	Packet Data Unit
PMC	Program Management Committee
PNP	Pulse Navigation Preprocessor
POSIX	Portable Operating System Interface
PSM	Platform Specific Model
PTC	Platform Technology Committee

Appendix A. Acronyms

Acronym	Meaning
RT	Remote Terminal
RTCA	RTCA, Inc. (formerly Radio Technical Commission for Aeronautics)
RTCP	Real-Time Communication Protocols
RTMT	Real Time Model Task
SAE	Society of Automotive Engineers
SAI	Systems Architecture and Interfaces
SAP	Service Access Points
SATCOM	Satellite Communication
SC	Special Committee
SCA	Software Communications Architecture
SDO	Standards Developing Organizations
SDR	Software Defined Radio
SDU	Service Data Unit
SDRF	Software Defined Radio Forum
SFF	Small Form Factor
SGD	Symbol Graphical Definition
SIG	Special Interest Group
SRU	Shop Replaceable Unit
SSTC	Software Systems Technical Committee
STC	Supplemental Type Certificate
S-TIF	Sensor Traffic Information File
TACP	Tactical Air Control Party (USAF)
TAR	Technology Assessment Reports
TAWS	Terrain Awareness and Warning System
TC	Technical Committee
TC	Type Certificate
TCO	Total Cost of Ownership
TOD	Time of Day Distribution
TPC	Technical Policy Committee
TRANSEC	Transmission Security
TSO	Technical Standard Order
TSU	Traffic Surveillance Unit
TTP	Time Triggered Protocol
UAT	Universal Access Transceiver
UAV	Unmanned Air Vehicles
UGV	Unmanned Ground Vehicles
UMF	Universal Match Filter

Appendix A. Acronyms

Acronym	Meaning
UML	Unified Modeling Language
VDL	VHF Digital Link
VHDL	Virtual Hardware Development Language
VHF	Very High Frequency
VHSIC	Very High Speed Integrated Circuits
WG	Working Group
WNW	Wideband Network Waveform
WXR	Weather Radar
XCVR	Receiver/Exciter Transceiver
XML	Extensible Markup Language

JTRS Joint Program Office

1777 North Kent Street
Suite 2000
Arlington, VA 22209
703-588-1056
DSN: 425-1056
FAX: 703-588-1361

Program Directors
Col Steven MacLaird, USAF, Director
COL Glen Lambkin, USA, Deputy Director

Cluster Contacts

JTRS JPO Cluster Liaisons

Cluster 1
703-696-0478
jtrs.cluster1.@hqda.army.mil

Cluster 2
703-588-1064
jtrs.cluster2@hqda.army.mil

AMF Program
703-588-1198
Jtrs.amf@hqda.army.mil

Cluster 5
703-588-1064
jtrs.cluster5@hqda.army.mil

JTRS Cluster Program Management Office Contacts

Cluster 1
http://peoc3t.monmouth.army.mil/WIN-T/JTRS1.html

Cluster 2
813-281-0560

AMF Program
781-271-5902

Cluster 5
732-532-3924

Contracts
703-588-0201
jtrs.contracts@hqda.army.mil

Cost and Budget
703-588-0748
jtrs.budget@hqda.army.mil

Domestic (non-DoD) Initiatives
703-588-0532
jtrs.domestic@hqda.army.mil

International Initiatives
703-588-0532
jtrs.international@hqda.army.mil

Logistics Support
703-588-1076
jtrs.logistics@hqda.army.mil

Public Relations/Media Inquiries

JPO PR Liaison
703-588-1351
jtrs.pr@hqda.army.mil

US Army Public Affairs Office
703-697-4314

Service Liaisons

Army
703-588-0532
jtrs.army@hqda.army.mil

Navy
703-588-0566
jtrs.navy@hqda.army.mil

Marine Corps
703-588-1064
jtrs.marines@hqda.army.mil

Air Force
703-588-1244
jtrs.usaf@hqda.army.mil

Software Communications Architecture
703-588-1074
jtrs.sca@hqda.army.mil

Technology Management
703-588-0566
jtrs.techman@hqda.army.mil

Test and Evaluation
703-588-1182
jtrs.test@hqda.army.mil

Waveforms
703-588-1275
jtrs.waveforms@hqda.army.mil

Waivers
703-588-1244
jtrs.waivers@hqda.army.mil